FIG.1

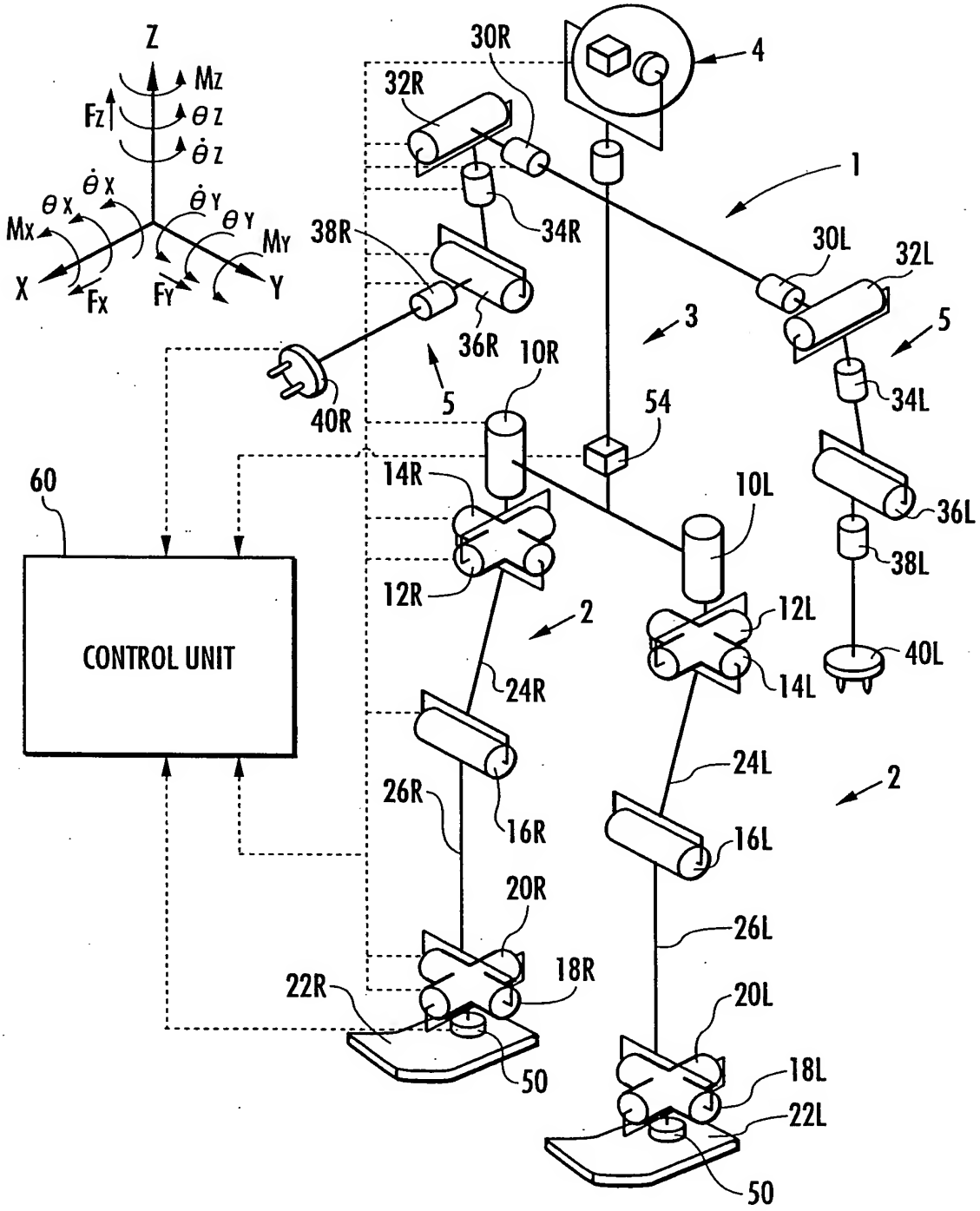

Z
Mz
Fz
θz
θ̇z
θ̇x
θx
θ̇y
θy
Mx
My
X
Y
Fx
Fy
30R
32R
4
1
34R
38R
30L
32L
3
5
36R
10R
5
34L
40R
54
60
14R
10L
36L
38L
12R
2
12L
40L
CONTROL UNIT
24R
14L
24L
2
26R
16R
16L
20R
26L
18R
22R
20L
18L
22L
50
50

FIG.2

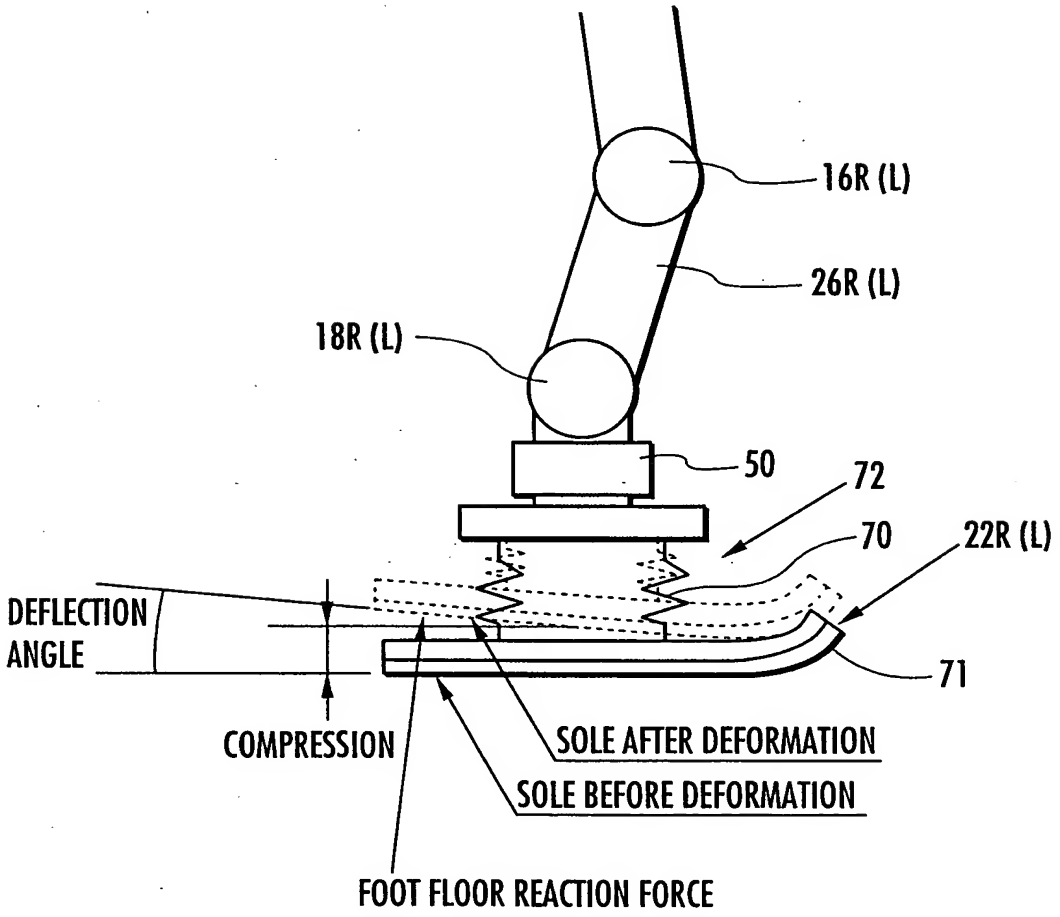

16R (L)
26R (L)
18R (L)
50
72
70
22R (L)
71
DEFLECTION ANGLE
COMPRESSION
SOLE AFTER DEFORMATION
SOLE BEFORE DEFORMATION
FOOT FLOOR REACTION FORCE

FIG.3

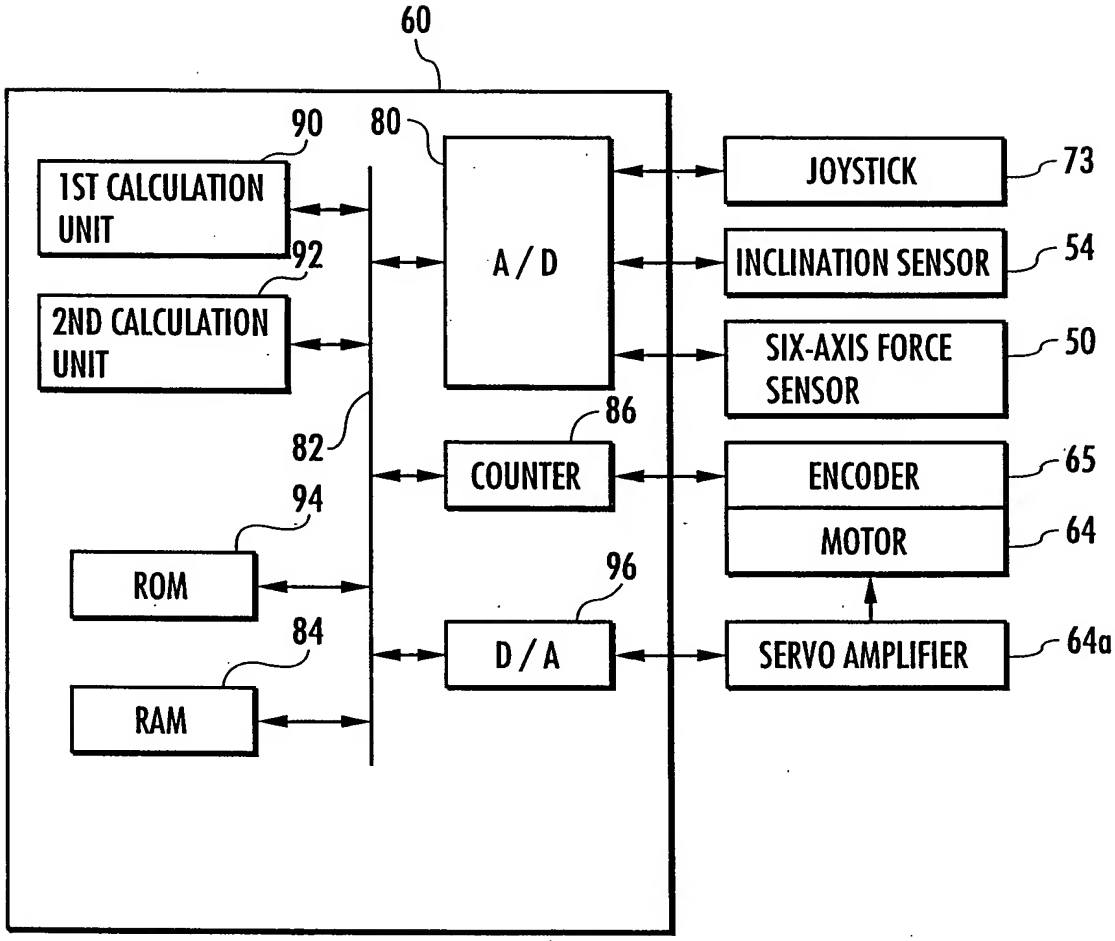

60
90
80
1ST CALCULATION UNIT
92
2ND CALCULATION UNIT
A / D
JOYSTICK
73
INCLINATION SENSOR
54
SIX-AXIS FORCE SENSOR
50
82
86
COUNTER
ENCODER
65
MOTOR
64
94
ROM
96
84
RAM
D / A
SERVO AMPLIFIER
64a

FIG.4

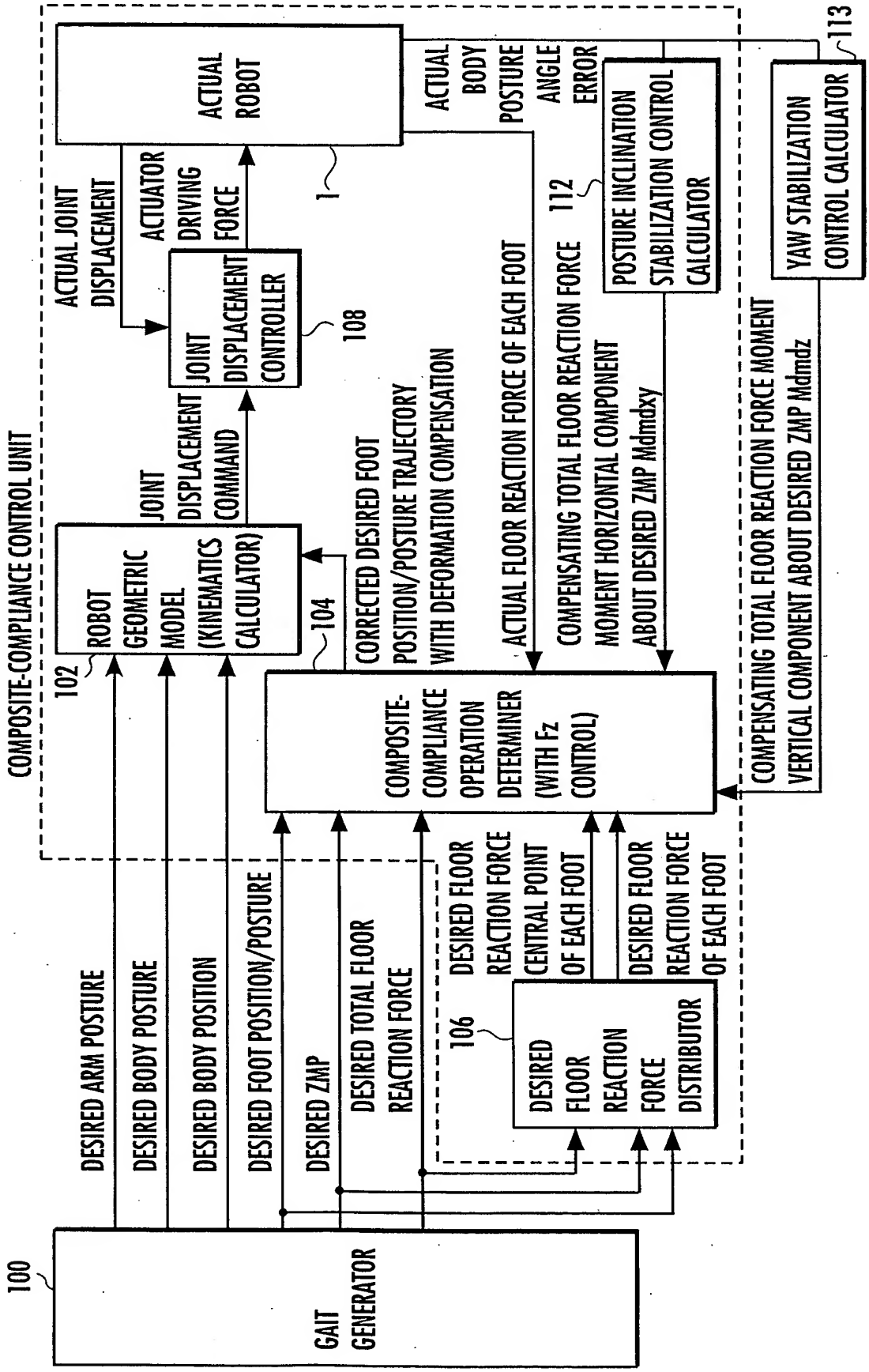

COMPOSITE-COMPLIANCE CONTROL UNIT
ACTUAL ROBOT
1
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
JOINT DISPLACEMENT CONTROLLER
108
JOINT DISPLACEMENT COMMAND
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
102
104
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
ACTUAL BODY POSTURE ANGLE ERROR
POSTURE INCLINATION STABILIZATION CONTROL CALCULATOR
112
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP Mdmdxy
YAW STABILIZATION CONTROL CALCULATOR
113
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT ABOUT DESIRED ZMP Mdmdz
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
DESIRED ARM POSTURE
DESIRED BODY POSTURE
DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
106
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
100
GAIT GENERATOR

FIG.5

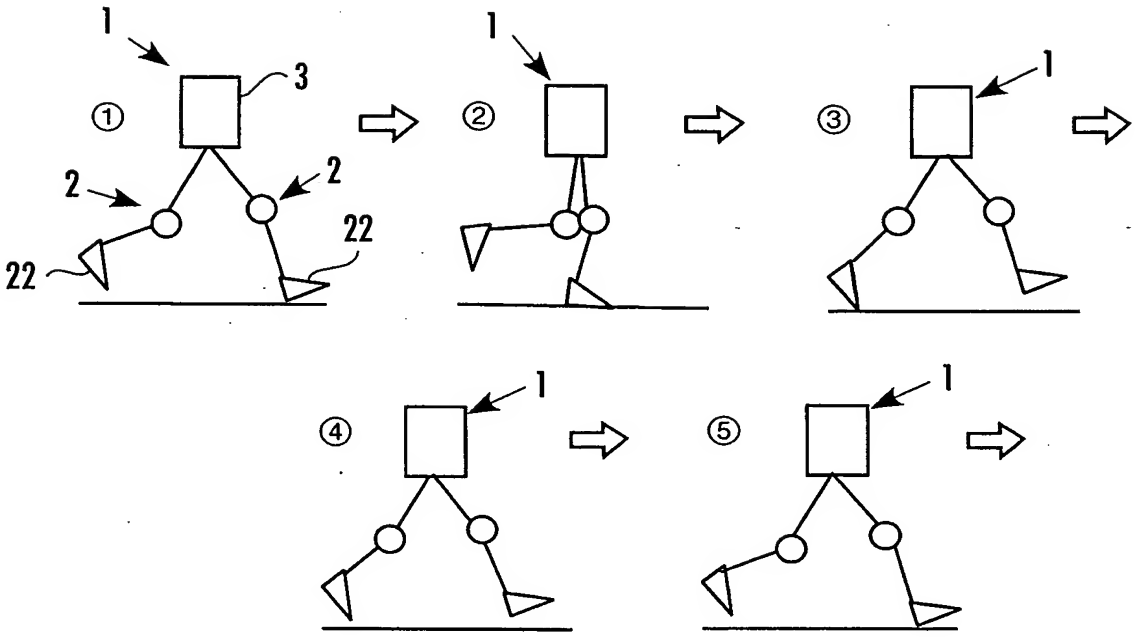


FIG.6

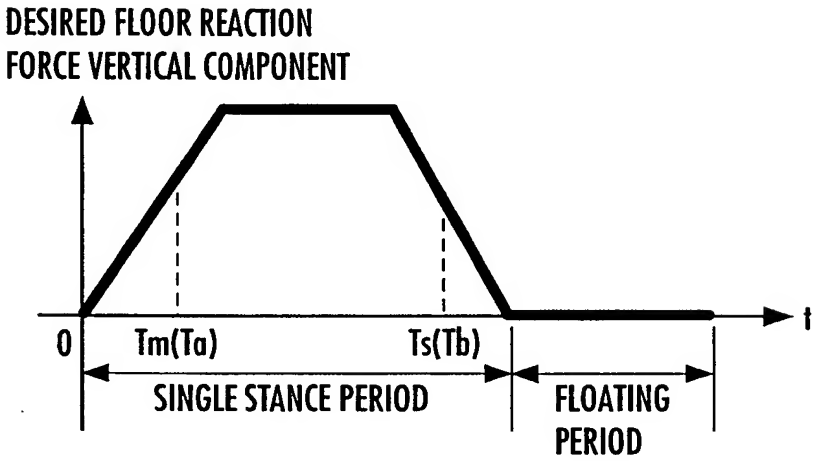

DESIRED FLOOR REACTION
FORCE VERTICAL COMPONENT
0
Tm(Ta)
Ts(Tb)
t
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.7

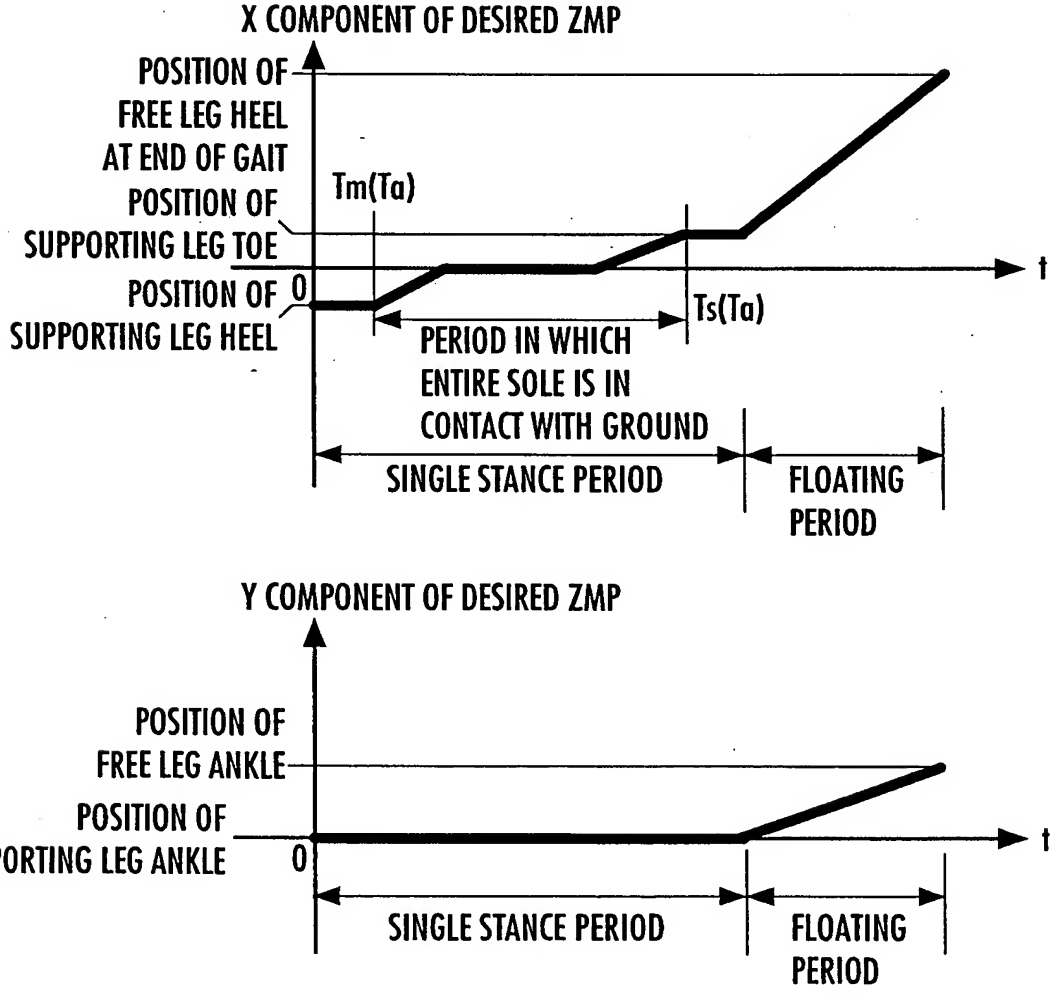

X COMPONENT OF DESIRED ZMP
POSITION OF
FREE LEG HEEL
AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
0
Tm(Ta)
Ts(Ta)
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD
Y COMPONENT OF DESIRED ZMP
POSITION OF
FREE LEG ANKLE
POSITION OF
SUPPORTING LEG ANKLE
0
t
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.8

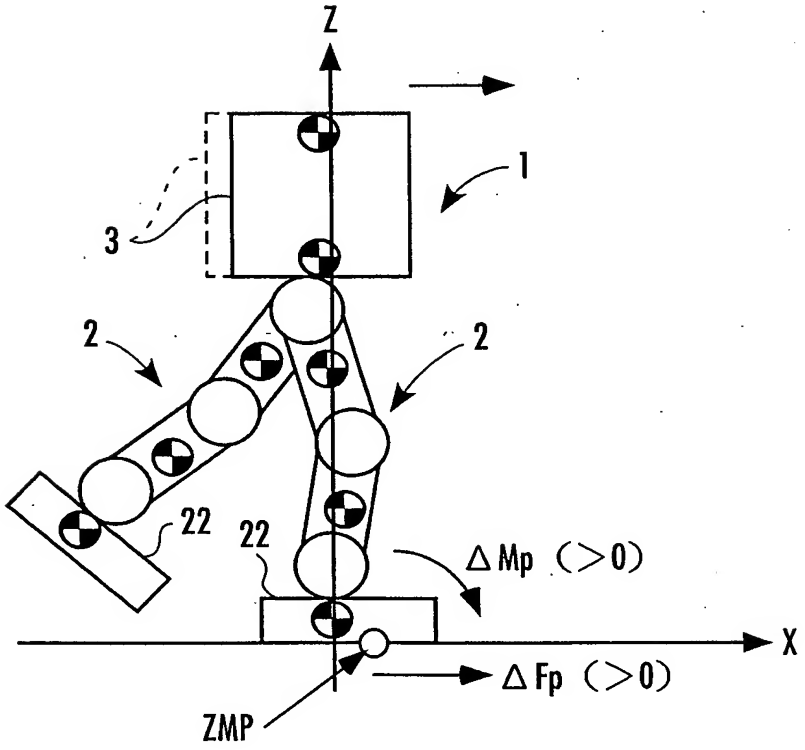


FIG.9

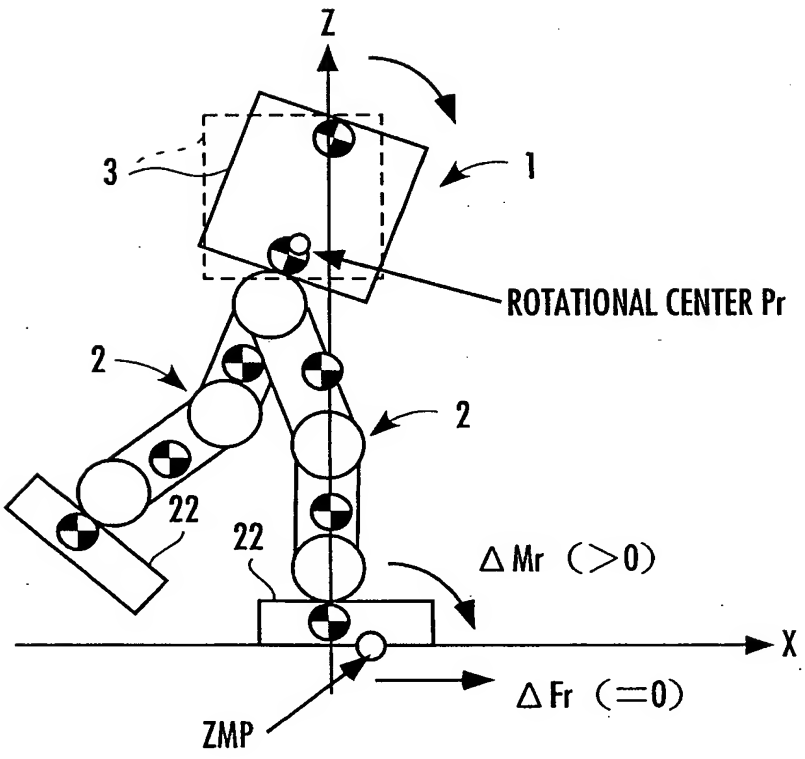


FIG.10

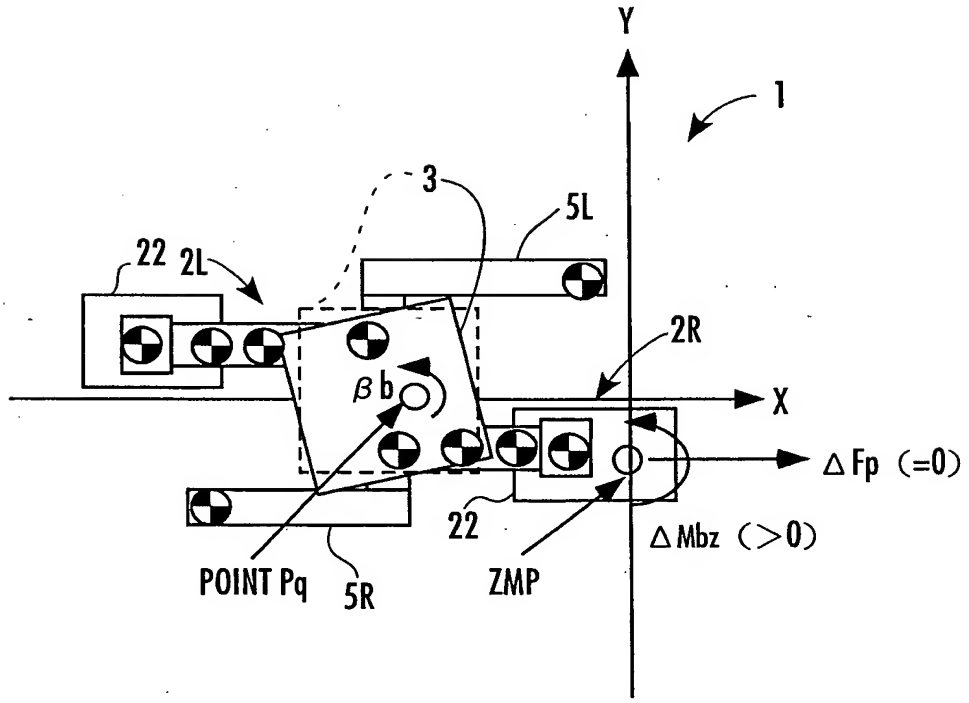


FIG.11(a)

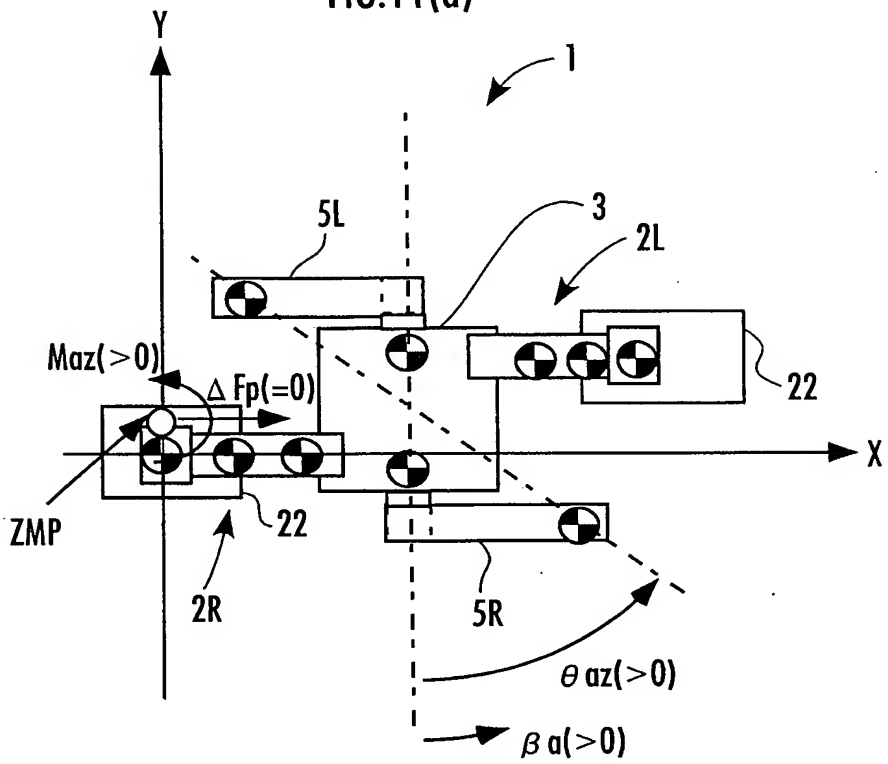


FIG.11(b)

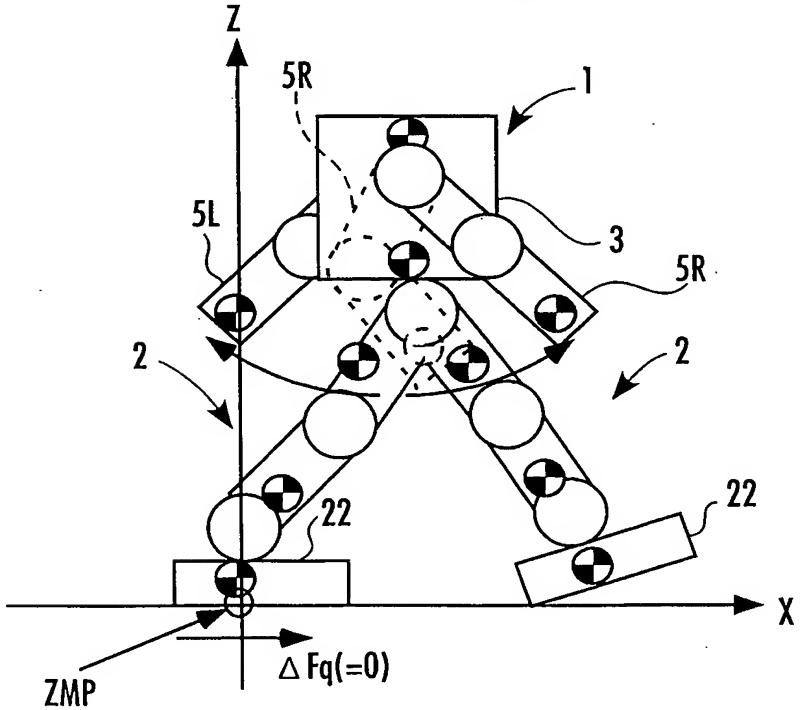


FIG.12

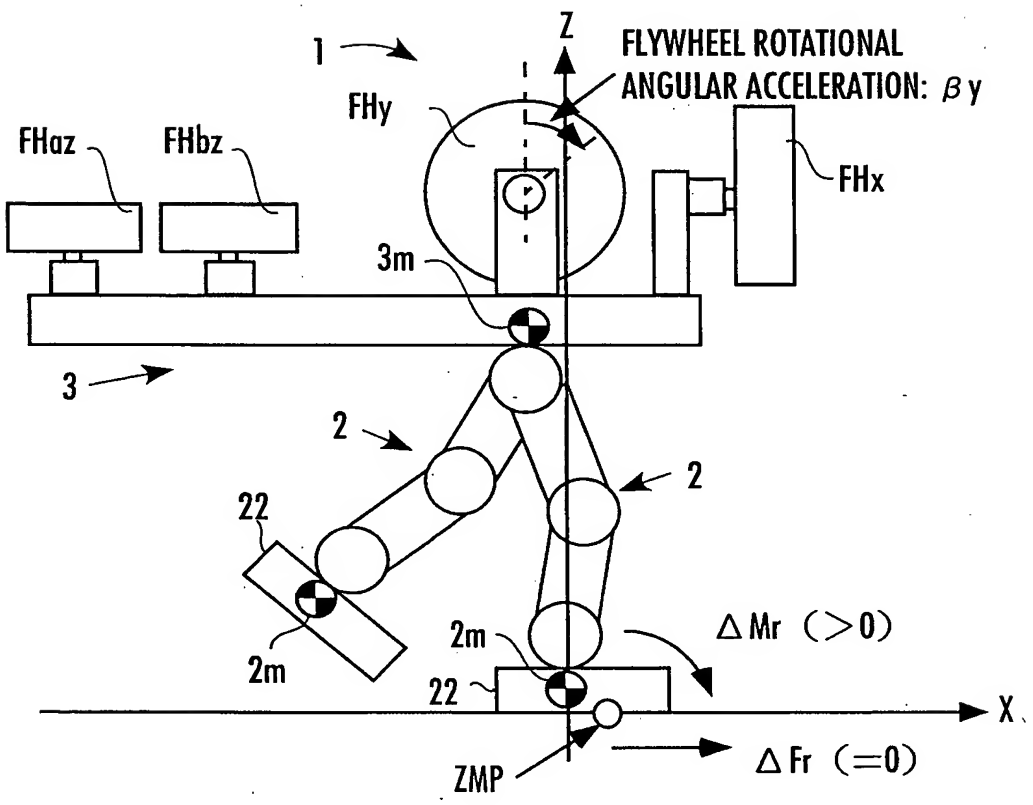

1
Z
FLYWHEEL ROTATIONAL ANGULAR ACCELERATION: βy
FHy
FHaz
FHbz
FHx
3m
3
2
2
22
2m
2m
ΔMr (>0)
22
X
ZMP
ΔFr (=0)

FIG.13

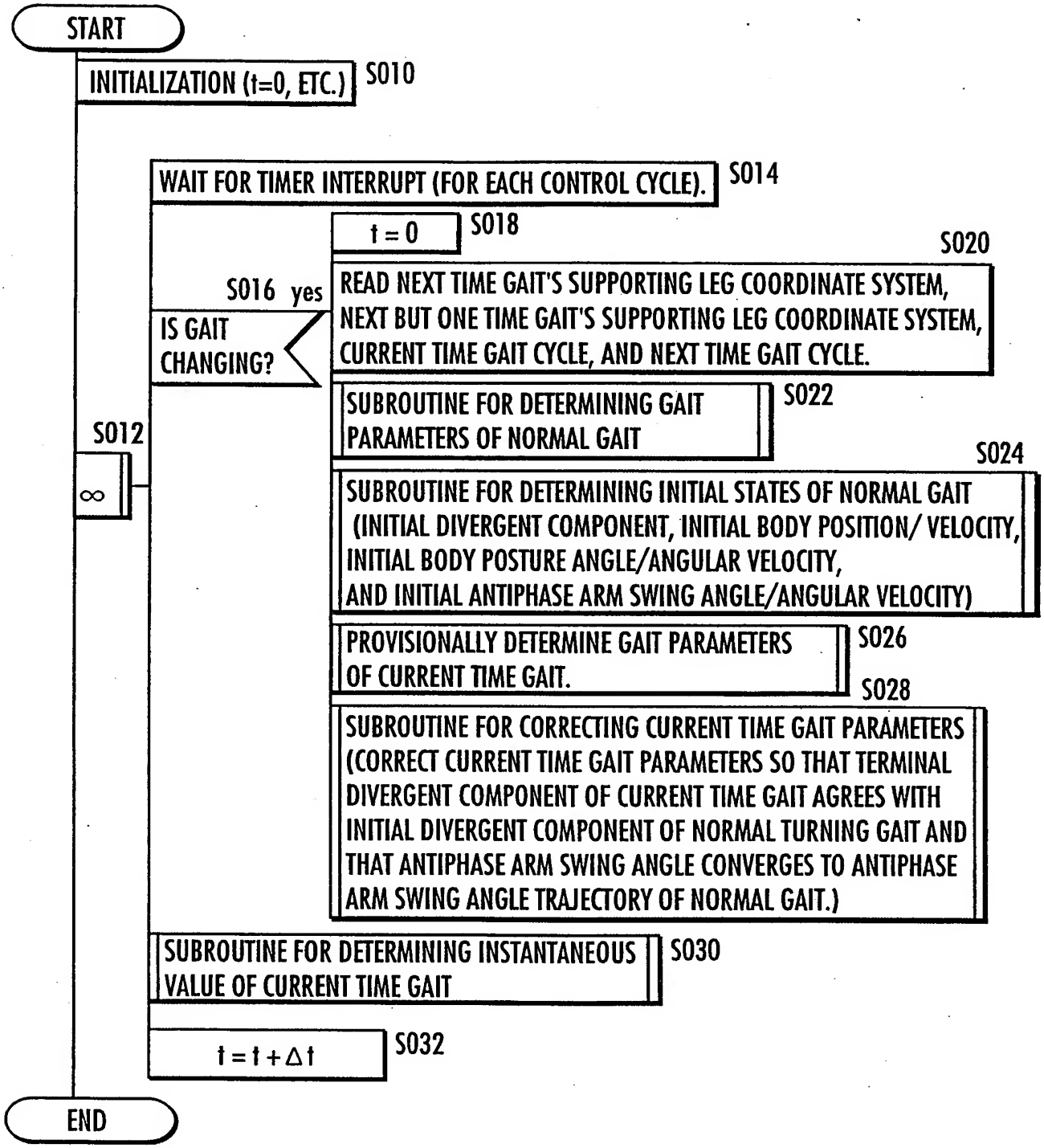

START
INITIALIZATION (t=0, ETC.)
S010
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S014
t = 0
S018
S020
S016 yes
IS GAIT CHANGING?
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S022
S012
∞
S024
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S026
S028
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT
S030
t = t + Δt
S032
END

FIG.14

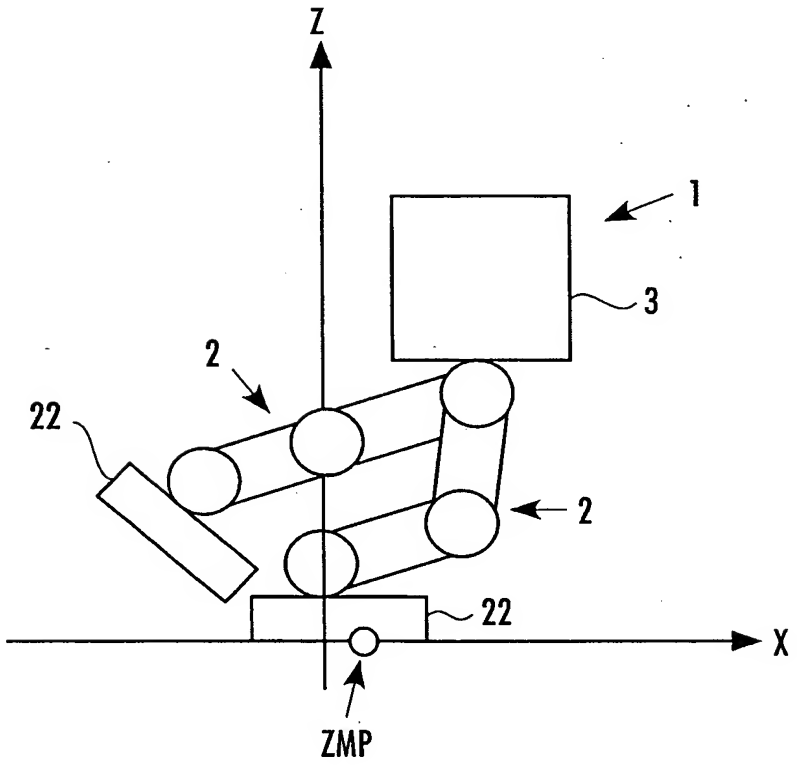


FIG.15

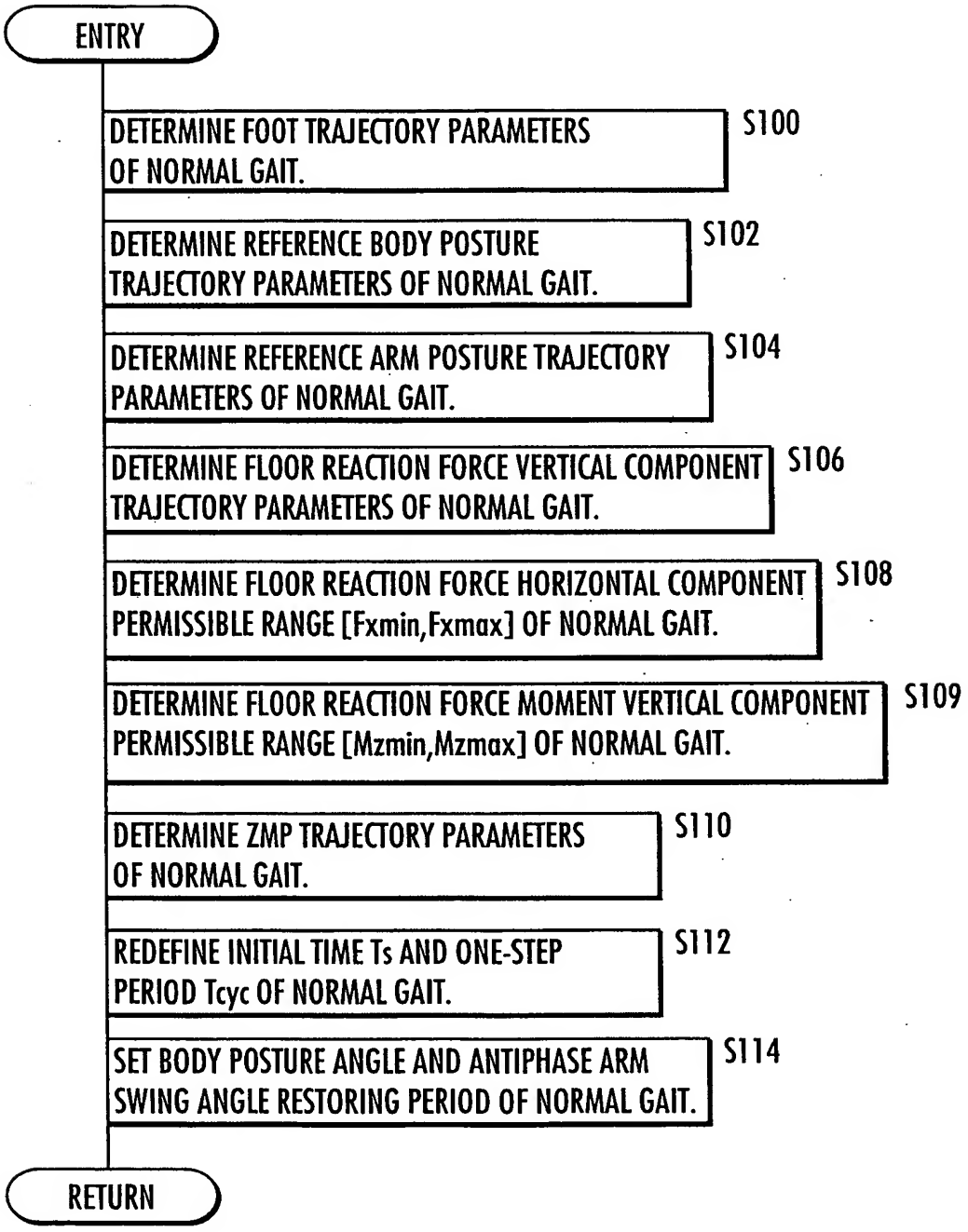

ENTRY
DETERMINE FOOT TRAJECTORY PARAMETERS OF NORMAL GAIT.
S100
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETERS OF NORMAL GAIT.
S102
DETERMINE REFERENCE ARM POSTURE TRAJECTORY PARAMETERS OF NORMAL GAIT.
S104
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETERS OF NORMAL GAIT.
S106
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF NORMAL GAIT.
S108
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] OF NORMAL GAIT.
S109
DETERMINE ZMP TRAJECTORY PARAMETERS OF NORMAL GAIT.
S110
REDEFINE INITIAL TIME Ts AND ONE-STEP PERIOD Tcyc OF NORMAL GAIT.
S112
SET BODY POSTURE ANGLE AND ANTIPHASE ARM SWING ANGLE RESTORING PERIOD OF NORMAL GAIT.
S114
RETURN

FIG.16

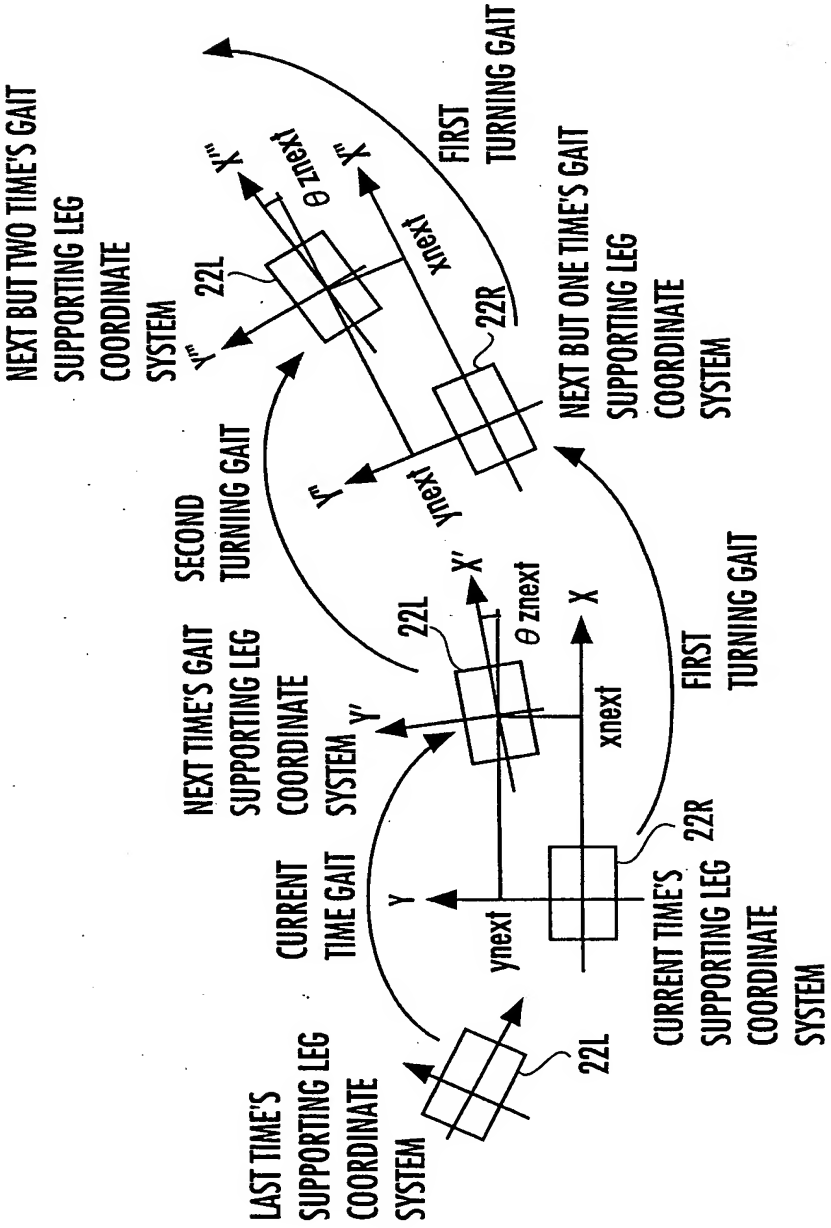

LAST TIME'S SUPPORTING LEG COORDINATE SYSTEM
CURRENT TIME GAIT
NEXT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
SECOND TURNING GAIT
NEXT BUT TWO TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
FIRST TURNING GAIT
NEXT BUT ONE TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
FIRST TURNING GAIT
CURRENT TIME'S SUPPORTING LEG COORDINATE SYSTEM
22L
22R
Y
ynext
X
xnext
θ znext
Y'
X'
Y''
X''
Y'''
X'''

FIG.17

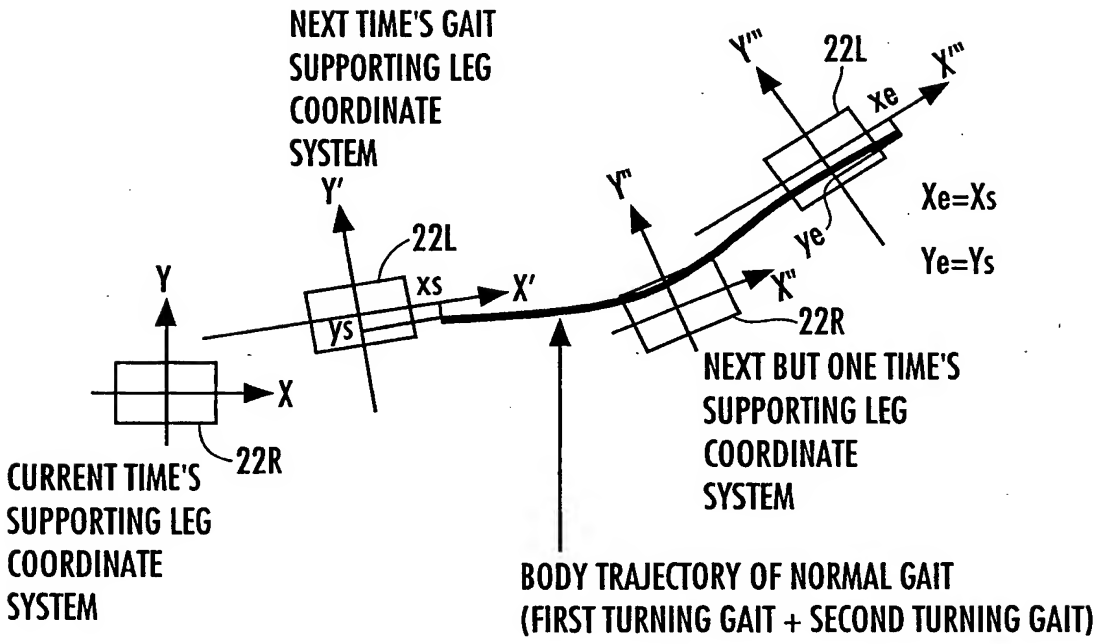

NEXT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
Y'
22L
xs
ys
X'
Y
X
22R
CURRENT TIME'S SUPPORTING LEG COORDINATE SYSTEM
Y"
Y'"
22L
X'"
xe
ye
Xe=Xs
Ye=Ys
X"
22R
NEXT BUT ONE TIME'S SUPPORTING LEG COORDINATE SYSTEM
BODY TRAJECTORY OF NORMAL GAIT
(FIRST TURNING GAIT + SECOND TURNING GAIT)

FIG.18

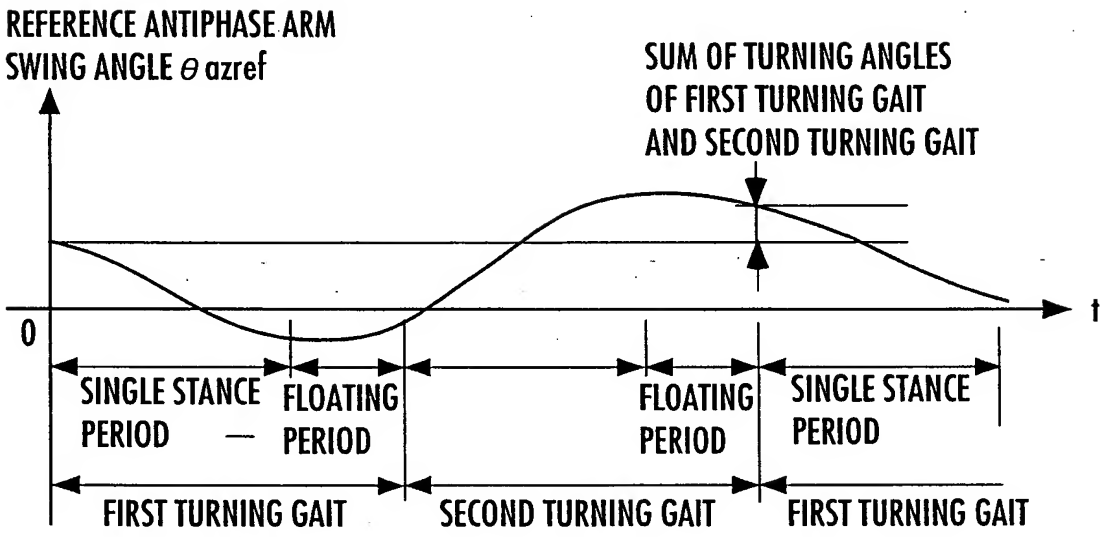

REFERENCE ANTIPHASE ARM SWING ANGLE θ azref
SUM OF TURNING ANGLES OF FIRST TURNING GAIT AND SECOND TURNING GAIT
0
t
SINGLE STANCE PERIOD
FLOATING PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT

FIG.19

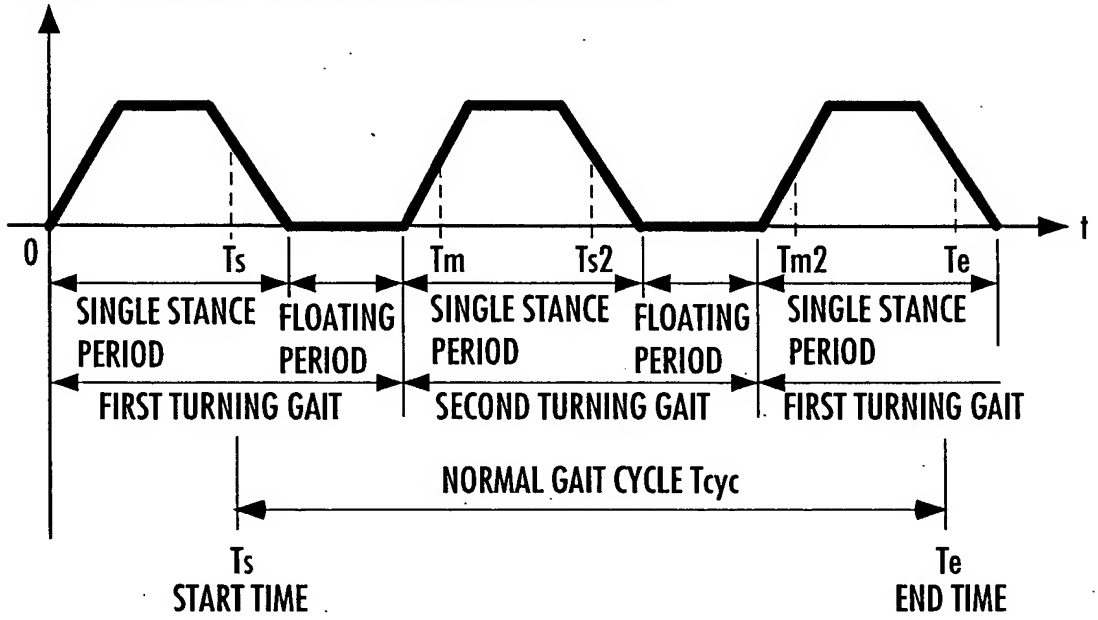

DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
0
Ts
Tm
Ts2
Tm2
Te
t
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.20

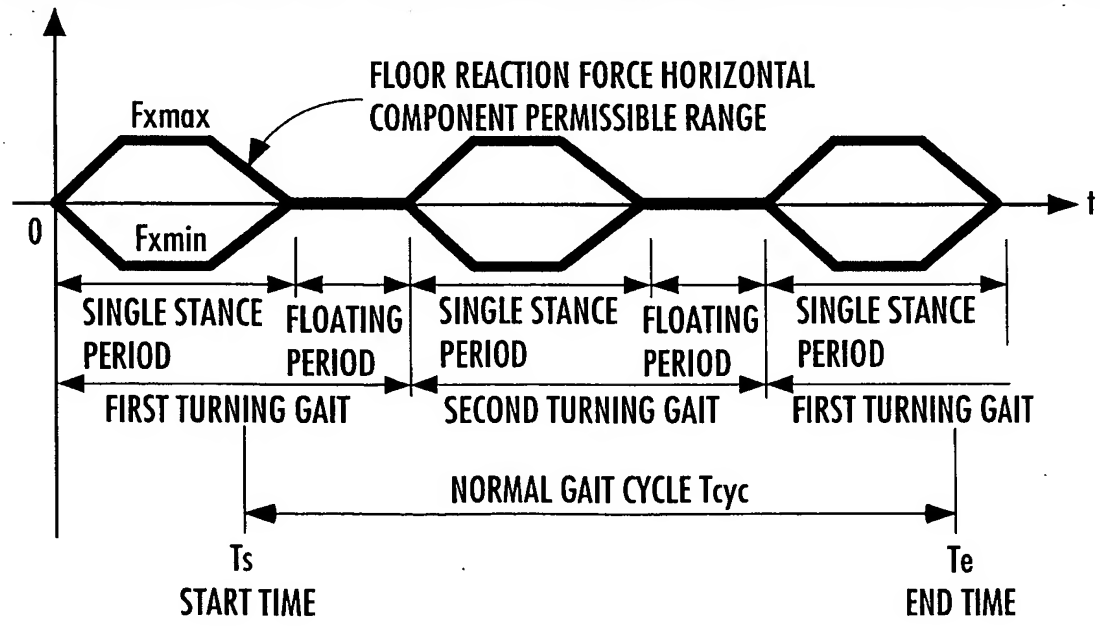

FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Fxmin
AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Fxmax
FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE
Fxmax
Fxmin
0
t
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.21

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Mzmin AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Mzmax

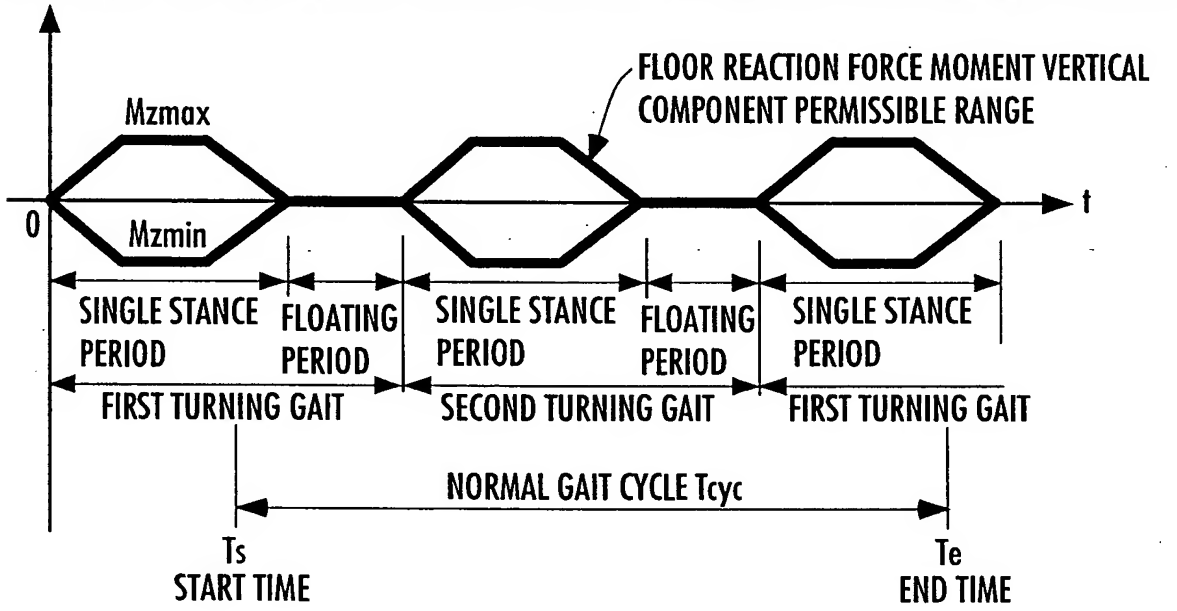


FIG.22

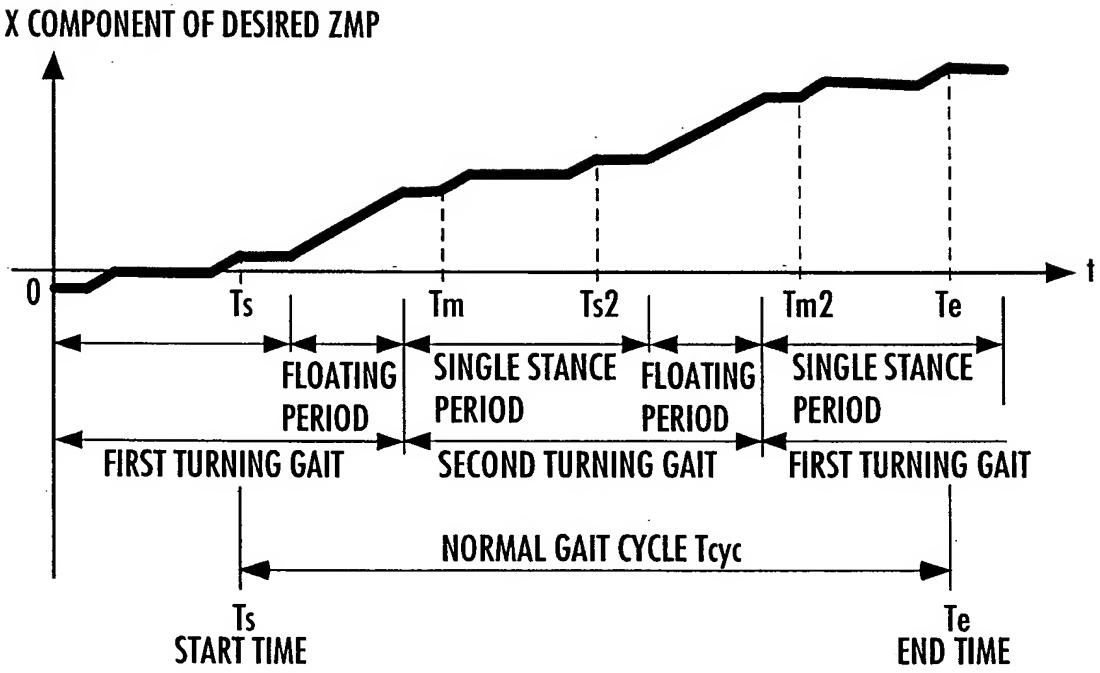

X COMPONENT OF DESIRED ZMP
0
t
Ts
Tm
Ts2
Tm2
Te
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.23

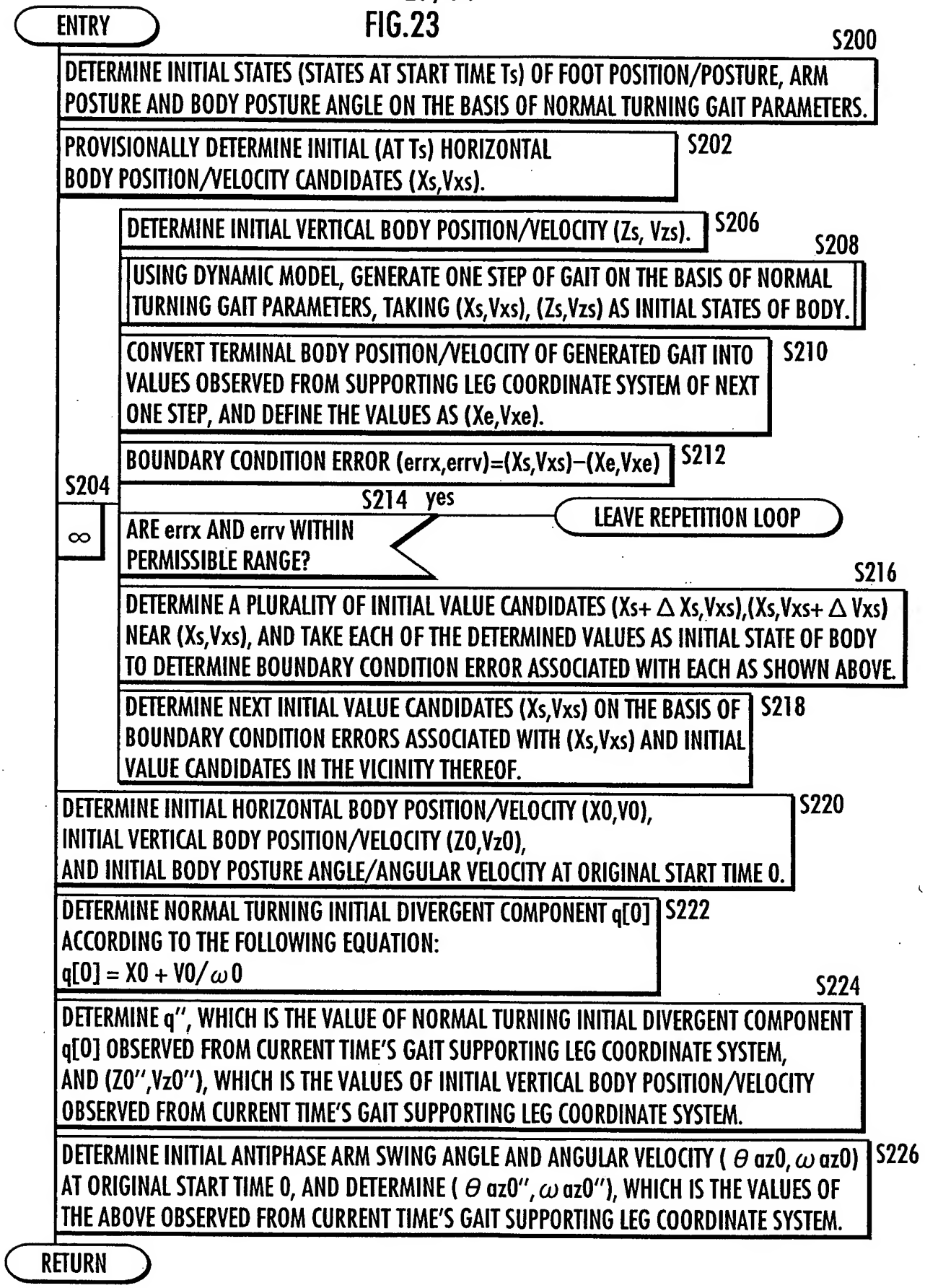

ENTRY
S200
DETERMINE INITIAL STATES (STATES AT START TIME Ts) OF FOOT POSITION/POSTURE, ARM POSTURE AND BODY POSTURE ANGLE ON THE BASIS OF NORMAL TURNING GAIT PARAMETERS.
PROVISIONALLY DETERMINE INITIAL (AT Ts) HORIZONTAL BODY POSITION/VELOCITY CANDIDATES (Xs,Vxs).
S202
DETERMINE INITIAL VERTICAL BODY POSITION/VELOCITY (Zs, Vzs).
S206
S208
USING DYNAMIC MODEL, GENERATE ONE STEP OF GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETERS, TAKING (Xs,Vxs), (Zs,Vzs) AS INITIAL STATES OF BODY.
CONVERT TERMINAL BODY POSITION/VELOCITY OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT ONE STEP, AND DEFINE THE VALUES AS (Xe,Vxe).
S210
BOUNDARY CONDITION ERROR (errx,errv)=(Xs,Vxs)−(Xe,Vxe)
S212
S204
∞
S214
yes
ARE errx AND errv WITHIN PERMISSIBLE RANGE?
LEAVE REPETITION LOOP
S216
DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (Xs+ Δ Xs,Vxs),(Xs,Vxs+ Δ Vxs) NEAR (Xs,Vxs), AND TAKE EACH OF THE DETERMINED VALUES AS INITIAL STATE OF BODY TO DETERMINE BOUNDARY CONDITION ERROR ASSOCIATED WITH EACH AS SHOWN ABOVE.
DETERMINE NEXT INITIAL VALUE CANDIDATES (Xs,Vxs) ON THE BASIS OF BOUNDARY CONDITION ERRORS ASSOCIATED WITH (Xs,Vxs) AND INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.
S218
DETERMINE INITIAL HORIZONTAL BODY POSITION/VELOCITY (X0,V0), INITIAL VERTICAL BODY POSITION/VELOCITY (Z0,Vz0), AND INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY AT ORIGINAL START TIME 0.
S220
DETERMINE NORMAL TURNING INITIAL DIVERGENT COMPONENT q[0] ACCORDING TO THE FOLLOWING EQUATION:
q[0] = X0 + V0/ω0
S222
DETERMINE q'', WHICH IS THE VALUE OF NORMAL TURNING INITIAL DIVERGENT COMPONENT q[0] OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM, AND (Z0'',Vz0''), WHICH IS THE VALUES OF INITIAL VERTICAL BODY POSITION/VELOCITY OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM.
S224
DETERMINE INITIAL ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY (θ az0, ω az0) AT ORIGINAL START TIME 0, AND DETERMINE (θ az0'', ω az0''), WHICH IS THE VALUES OF THE ABOVE OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM.
S226
RETURN

FIG.24

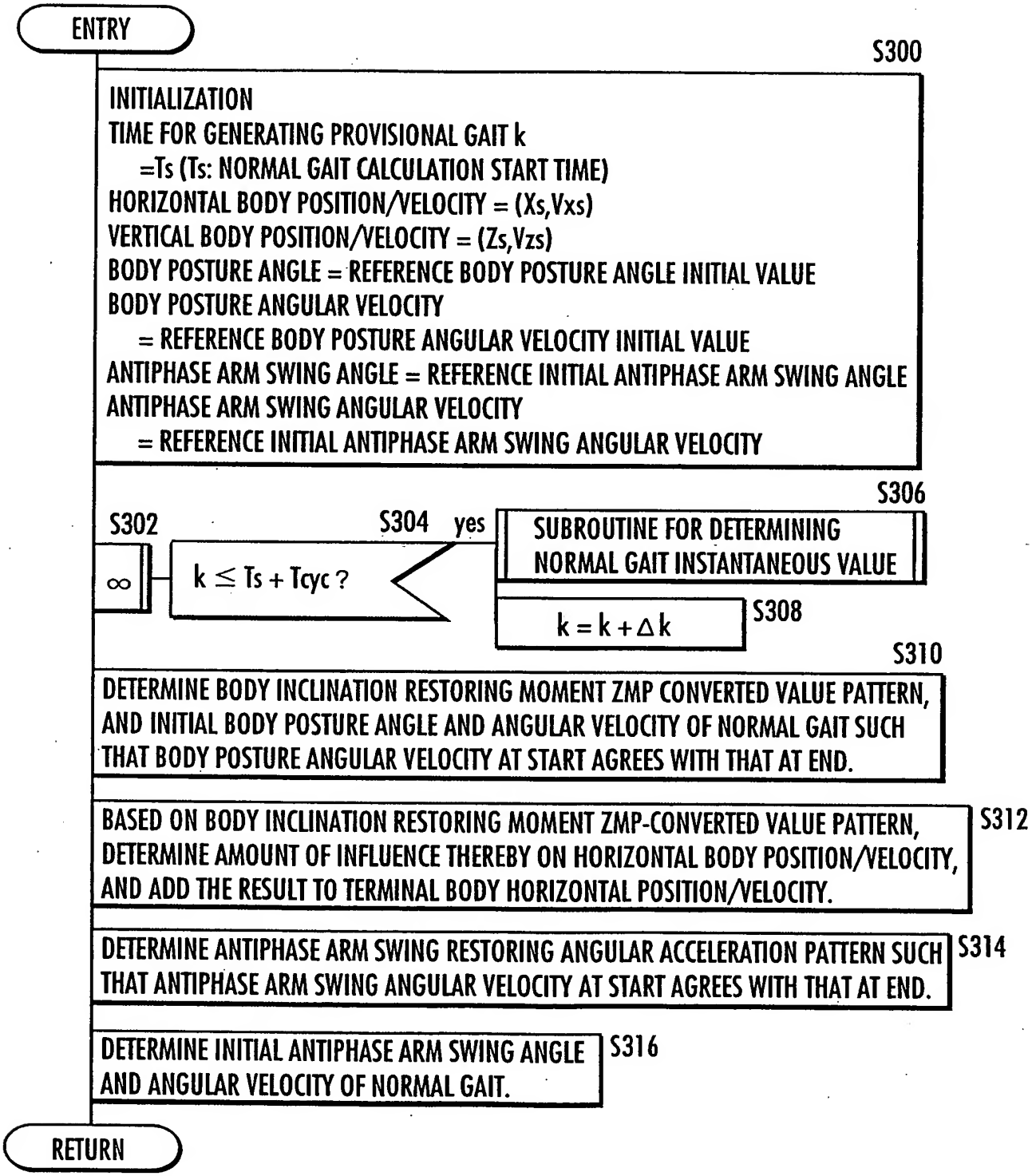

ENTRY
S300
INITIALIZATION
TIME FOR GENERATING PROVISIONAL GAIT k
=Ts (Ts: NORMAL GAIT CALCULATION START TIME)
HORIZONTAL BODY POSITION/VELOCITY = (Xs,Vxs)
VERTICAL BODY POSITION/VELOCITY = (Zs,Vzs)
BODY POSTURE ANGLE = REFERENCE BODY POSTURE ANGLE INITIAL VALUE
BODY POSTURE ANGULAR VELOCITY
= REFERENCE BODY POSTURE ANGULAR VELOCITY INITIAL VALUE
ANTIPHASE ARM SWING ANGLE = REFERENCE INITIAL ANTIPHASE ARM SWING ANGLE
ANTIPHASE ARM SWING ANGULAR VELOCITY
= REFERENCE INITIAL ANTIPHASE ARM SWING ANGULAR VELOCITY
S306
S302
S304
yes
SUBROUTINE FOR DETERMINING NORMAL GAIT INSTANTANEOUS VALUE
∞
k ≤ Ts + Tcyc ?
k = k + Δk
S308
S310
DETERMINE BODY INCLINATION RESTORING MOMENT ZMP CONVERTED VALUE PATTERN, AND INITIAL BODY POSTURE ANGLE AND ANGULAR VELOCITY OF NORMAL GAIT SUCH THAT BODY POSTURE ANGULAR VELOCITY AT START AGREES WITH THAT AT END.
BASED ON BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN, DETERMINE AMOUNT OF INFLUENCE THEREBY ON HORIZONTAL BODY POSITION/VELOCITY, AND ADD THE RESULT TO TERMINAL BODY HORIZONTAL POSITION/VELOCITY.
S312
DETERMINE ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN SUCH THAT ANTIPHASE ARM SWING ANGULAR VELOCITY AT START AGREES WITH THAT AT END.
S314
DETERMINE INITIAL ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY OF NORMAL GAIT.
S316
RETURN

FIG.25

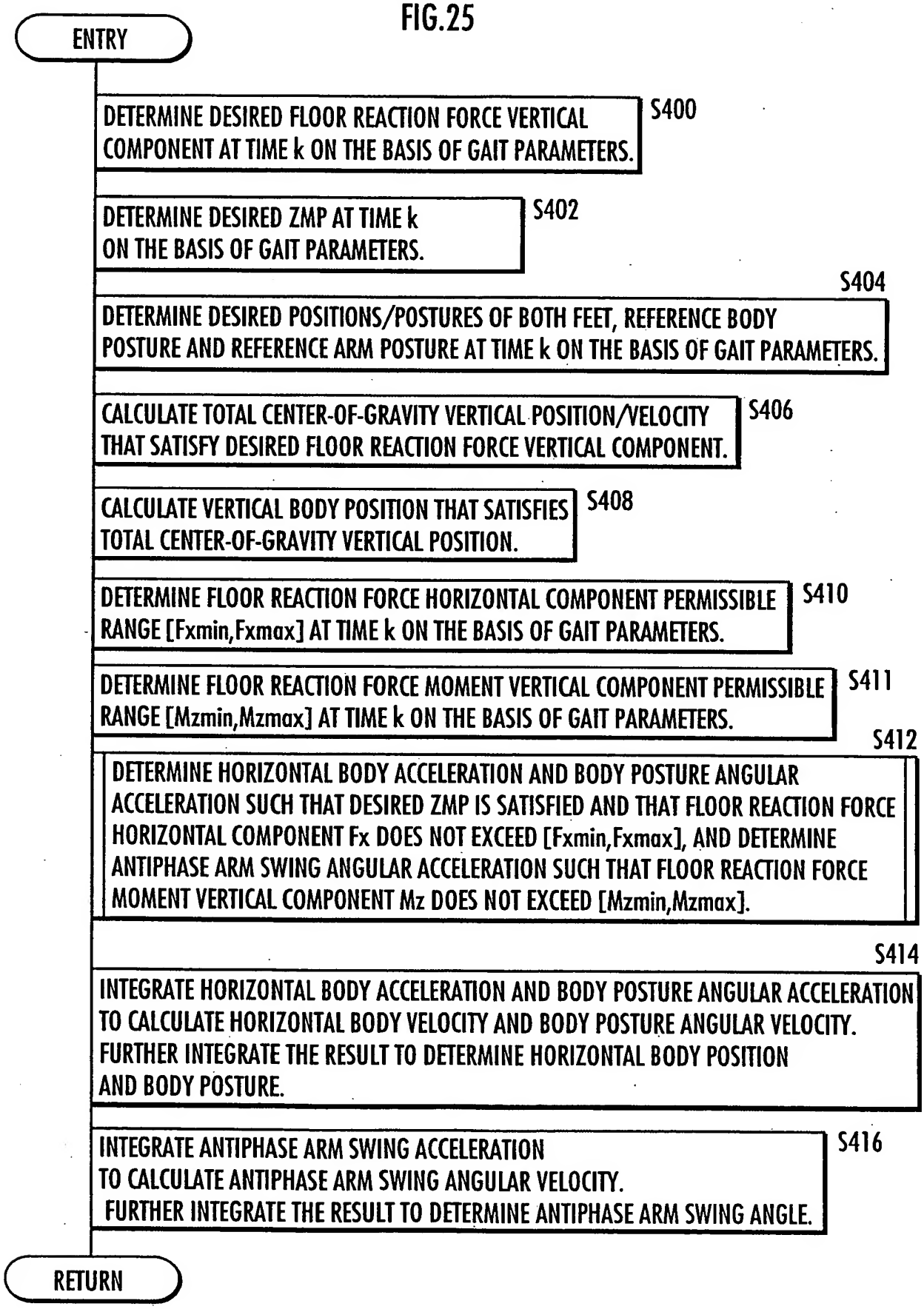

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S400
DETERMINE DESIRED ZMP AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S402
S404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT TIME k ON THE BASIS OF GAIT PARAMETERS.
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S406
CALCULATE VERTICAL BODY POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S408
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S410
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S411
S412
DETERMINE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT DESIRED ZMP IS SATISFIED AND THAT FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin,Fxmax], AND DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz DOES NOT EXCEED [Mzmin,Mzmax].
S414
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
S416
RETURN

FIG.26

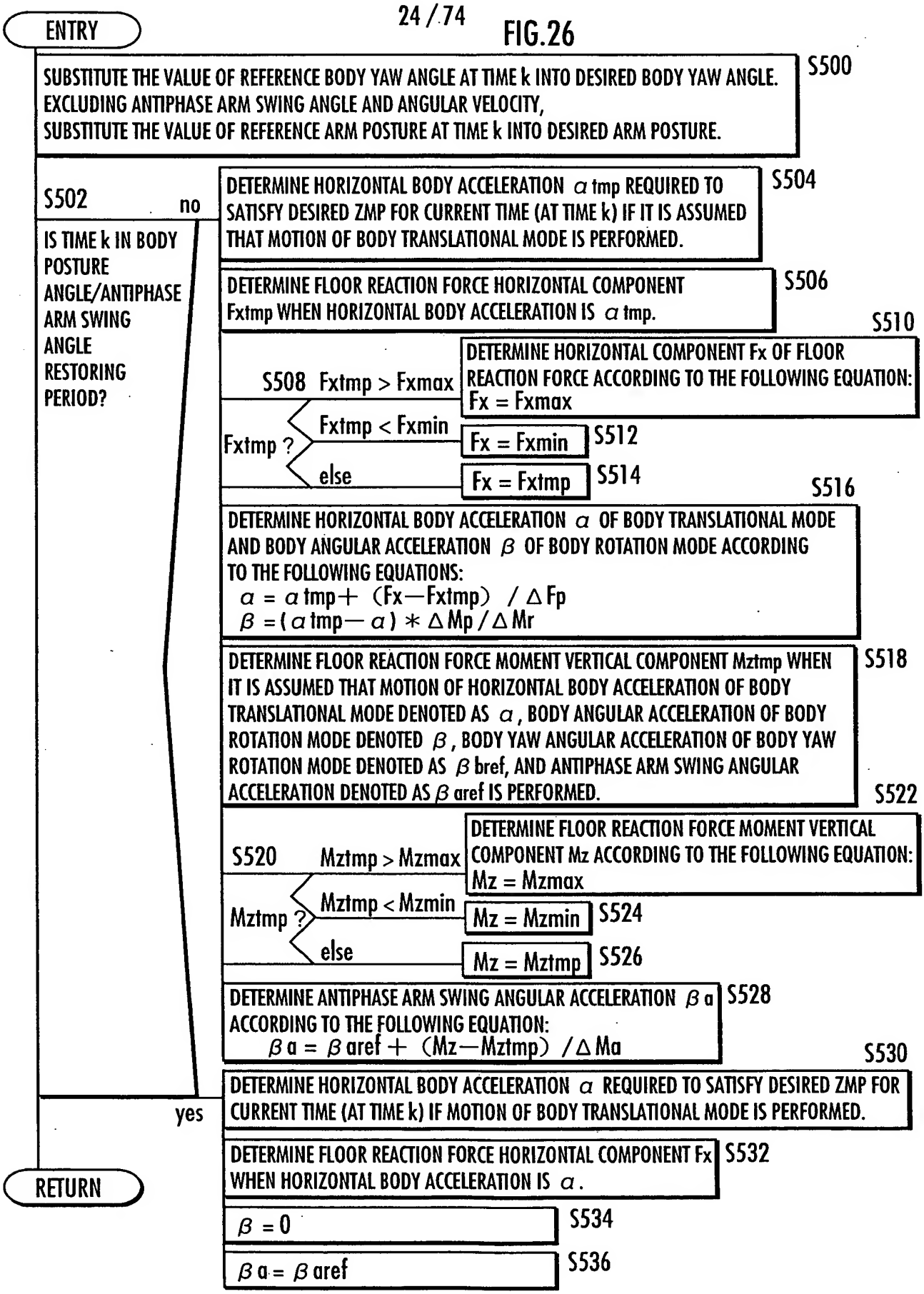

ENTRY
SUBSTITUTE THE VALUE OF REFERENCE BODY YAW ANGLE AT TIME k INTO DESIRED BODY YAW ANGLE. EXCLUDING ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY, SUBSTITUTE THE VALUE OF REFERENCE ARM POSTURE AT TIME k INTO DESIRED ARM POSTURE.
S500
S502
IS TIME k IN BODY POSTURE ANGLE/ANTIPHASE ARM SWING ANGLE RESTORING PERIOD?
no
yes
DETERMINE HORIZONTAL BODY ACCELERATION α tmp REQUIRED TO SATISFY DESIRED ZMP FOR CURRENT TIME (AT TIME k) IF IT IS ASSUMED THAT MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
S504
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp WHEN HORIZONTAL BODY ACCELERATION IS α tmp.
S506
S508 Fxtmp > Fxmax
DETERMINE HORIZONTAL COMPONENT Fx OF FLOOR REACTION FORCE ACCORDING TO THE FOLLOWING EQUATION: Fx = Fxmax
S510
Fxtmp ?
Fxtmp < Fxmin
Fx = Fxmin
S512
else
Fx = Fxtmp
S514
DETERMINE HORIZONTAL BODY ACCELERATION α OF BODY TRANSLATIONAL MODE AND BODY ANGULAR ACCELERATION β OF BODY ROTATION MODE ACCORDING TO THE FOLLOWING EQUATIONS:
α = α tmp + (Fx − Fxtmp) / ΔFp
β = (α tmp − α) * ΔMp / ΔMr
S516
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mztmp WHEN IT IS ASSUMED THAT MOTION OF HORIZONTAL BODY ACCELERATION OF BODY TRANSLATIONAL MODE DENOTED AS α, BODY ANGULAR ACCELERATION OF BODY ROTATION MODE DENOTED β, BODY YAW ANGULAR ACCELERATION OF BODY YAW ROTATION MODE DENOTED AS β bref, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION DENOTED AS β aref IS PERFORMED.
S518
S520 Mztmp > Mzmax
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz ACCORDING TO THE FOLLOWING EQUATION: Mz = Mzmax
S522
Mztmp ?
Mztmp < Mzmin
Mz = Mzmin
S524
else
Mz = Mztmp
S526
DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION β a ACCORDING TO THE FOLLOWING EQUATION:
β a = β aref + (Mz − Mztmp) / ΔMa
S528
DETERMINE HORIZONTAL BODY ACCELERATION α REQUIRED TO SATISFY DESIRED ZMP FOR CURRENT TIME (AT TIME k) IF MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
S530
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN HORIZONTAL BODY ACCELERATION IS α.
S532
β = 0
S534
β a = β aref
S536
RETURN

FIG.27

FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp
CREATED WITHOUT TAKING PERMISSIBLE RANGE INTO ACCOUNT

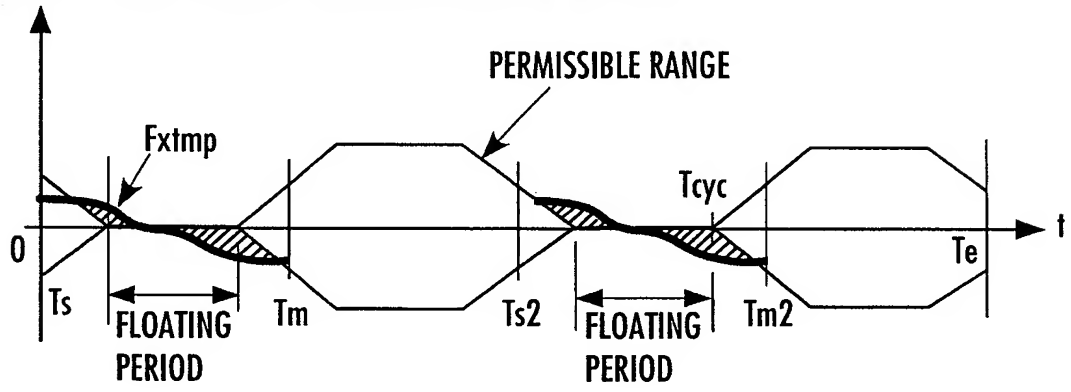


FIG.28

FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx
TAKING FLOOR REACTION FORCE HORIZONTAL COMPONENT
PERMISSIBLE RANGE INTO ACCOUNT

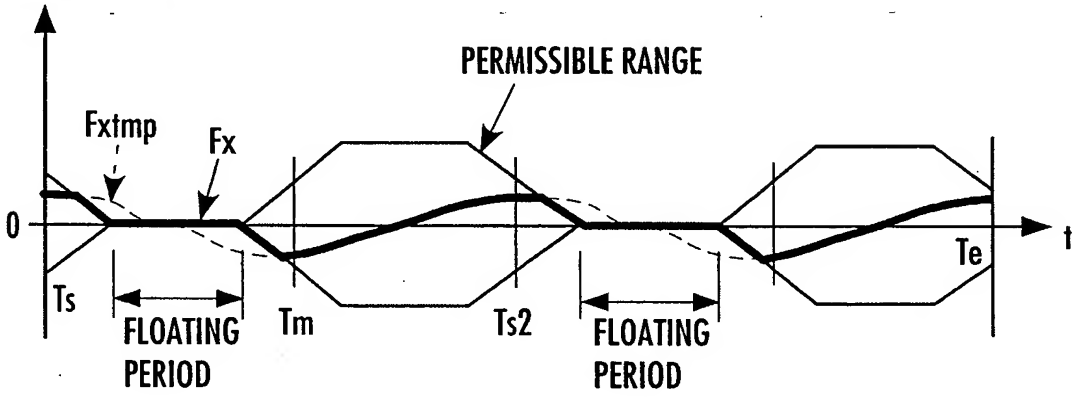


FIG.29

BODY INCLINATION ANGULAR ACCELERATION β

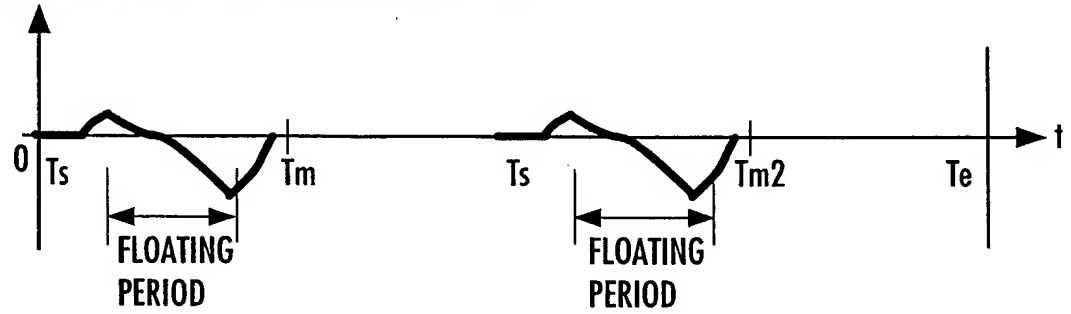


FIG.30

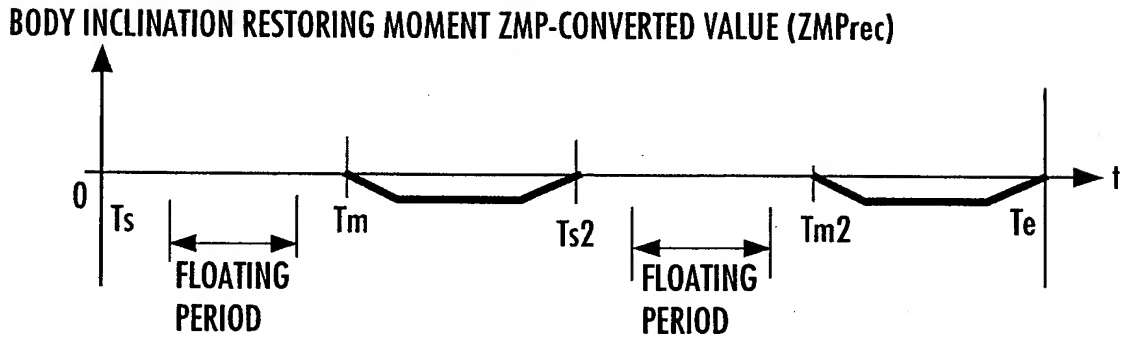

BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE (ZMPrec)
0
Ts
Tm
Ts2
Tm2
Te
t
FLOATING PERIOD
FLOATING PERIOD

FIG.31

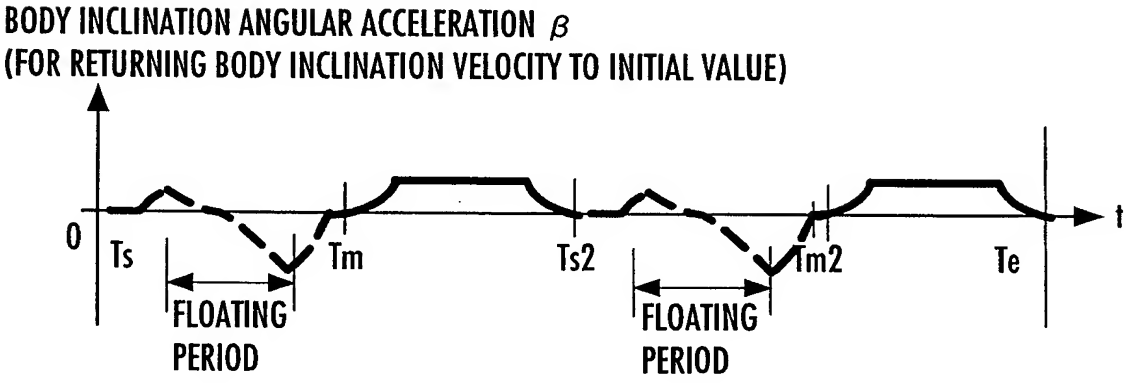

BODY INCLINATION ANGULAR ACCELERATION β
(FOR RETURNING BODY INCLINATION VELOCITY TO INITIAL VALUE)
0
Ts
Tm
Ts2
Tm2
Te
t
FLOATING PERIOD
FLOATING PERIOD

FIG.32

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mztmp CREATED WITHOUT TAKING PERMISSIBLE RANGE INTO ACCOUNT

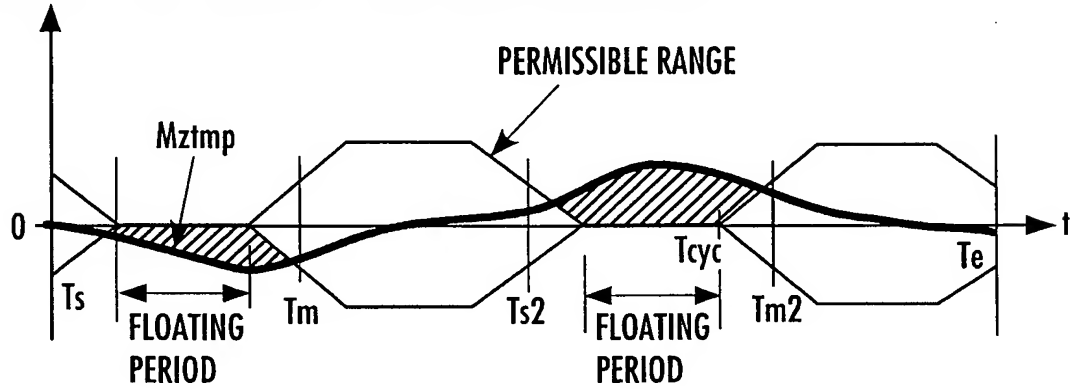


FIG.33

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz TAKING FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE INTO ACCOUNT

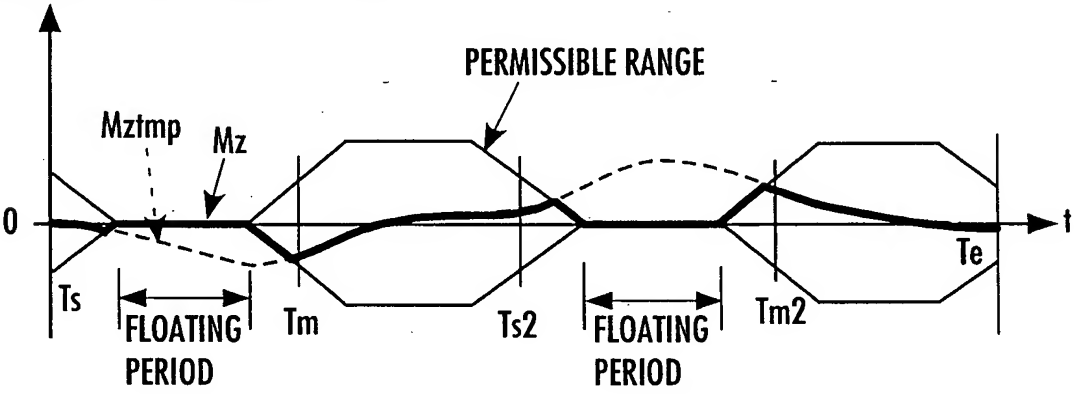


FIG.34

ANTIPHASE ARM SWING MOMENT (Maz)

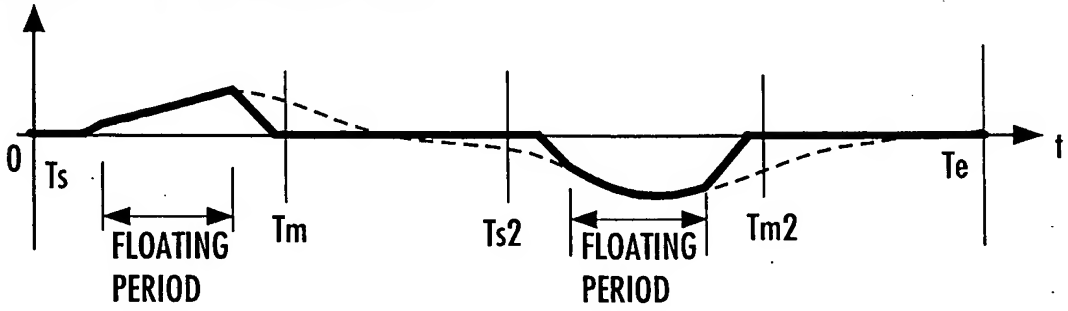


FIG.35

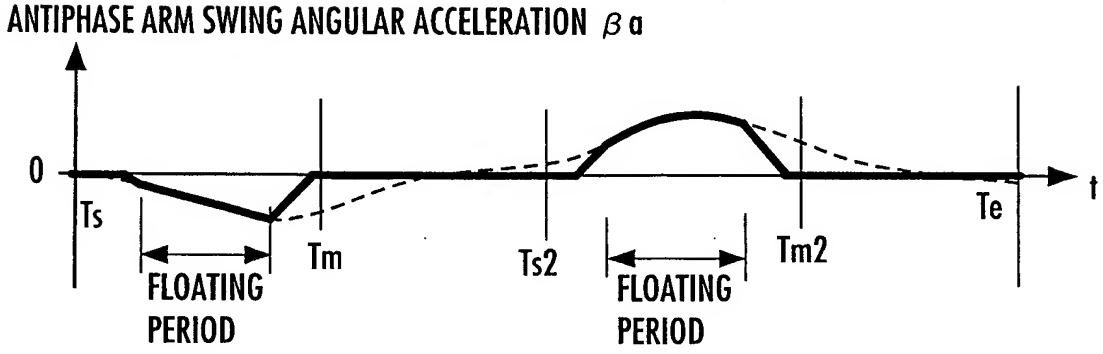


FIG.36

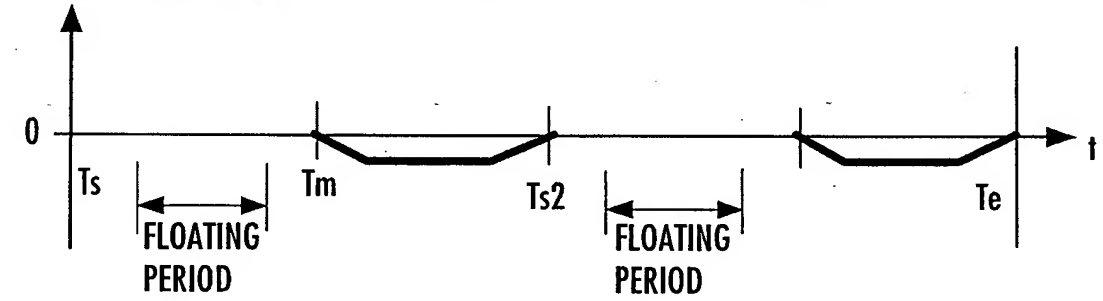


FIG.37

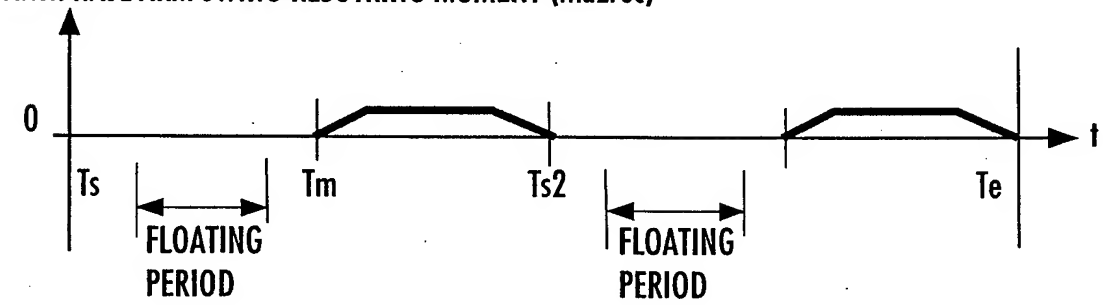


FIG.38

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz
TAKING FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT
PERMISSIBLE RANGE INTO ACCOUNT

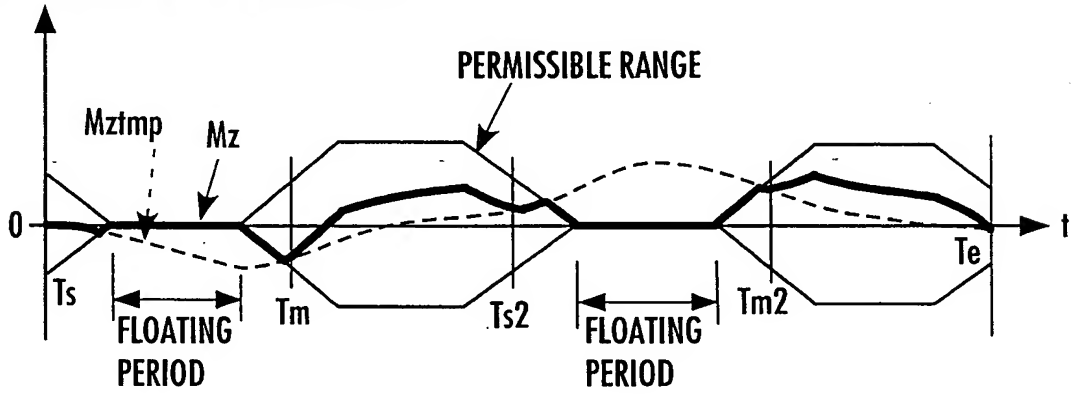


FIG.39

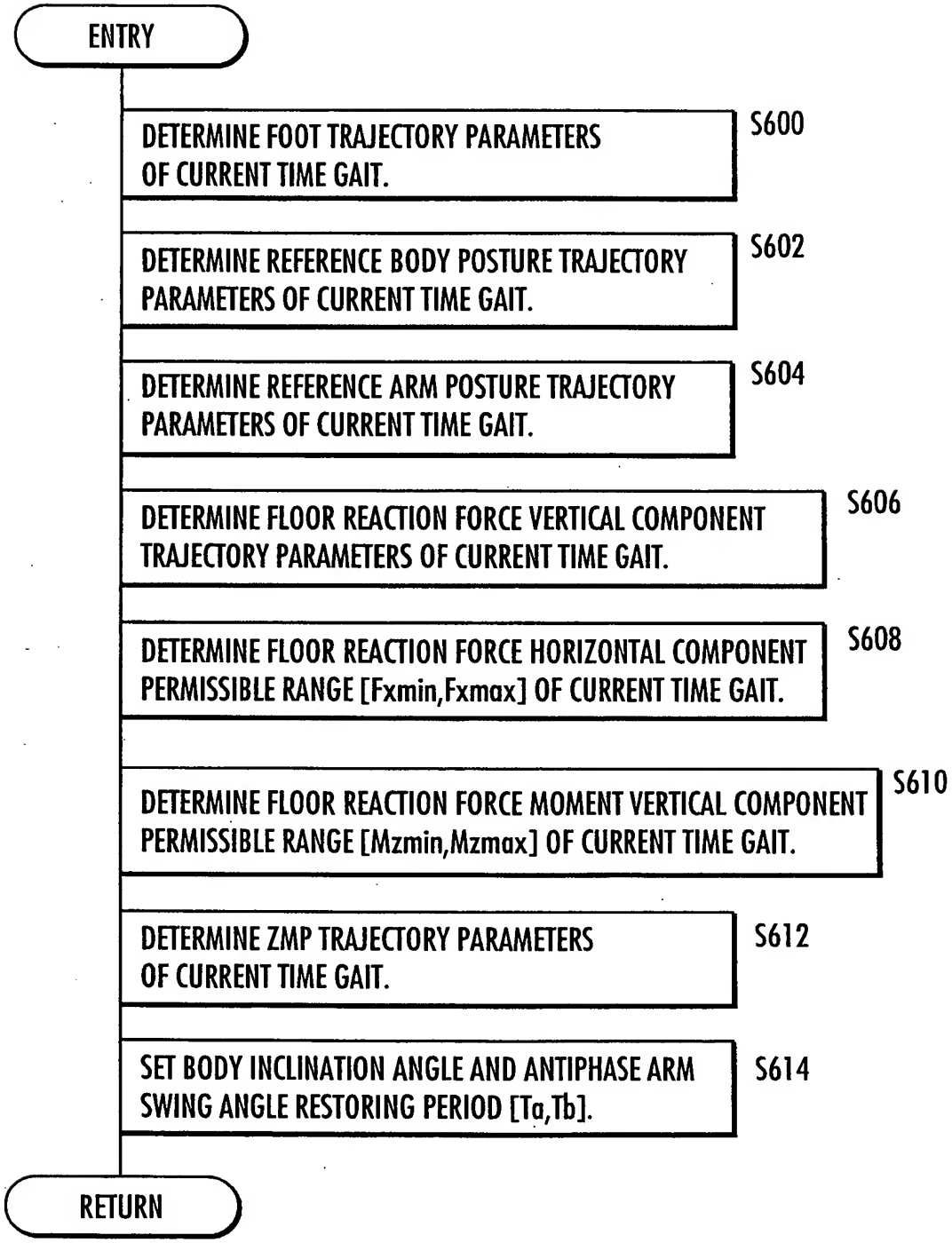

ENTRY
DETERMINE FOOT TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S600
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S602
DETERMINE REFERENCE ARM POSTURE TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S604
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S606
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF CURRENT TIME GAIT.
S608
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] OF CURRENT TIME GAIT.
S610
DETERMINE ZMP TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S612
SET BODY INCLINATION ANGLE AND ANTIPHASE ARM SWING ANGLE RESTORING PERIOD [Ta,Tb].
S614
RETURN

FIG.40

FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Fxmin AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Fxmax

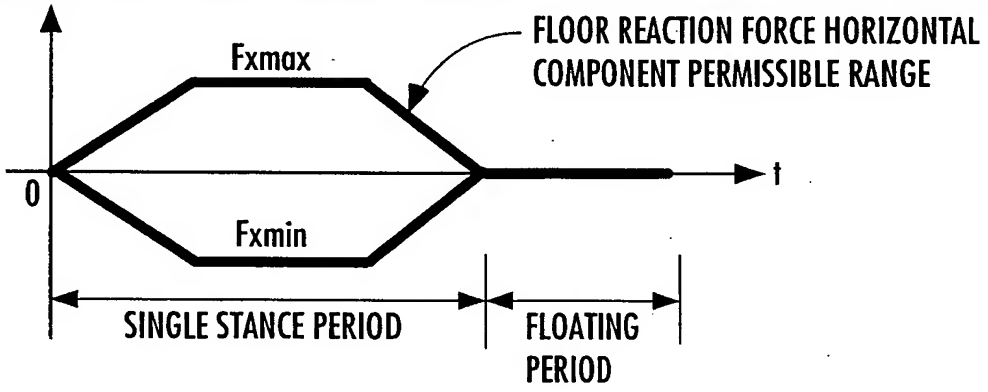


FIG.41

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Mzmin AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Mzmax

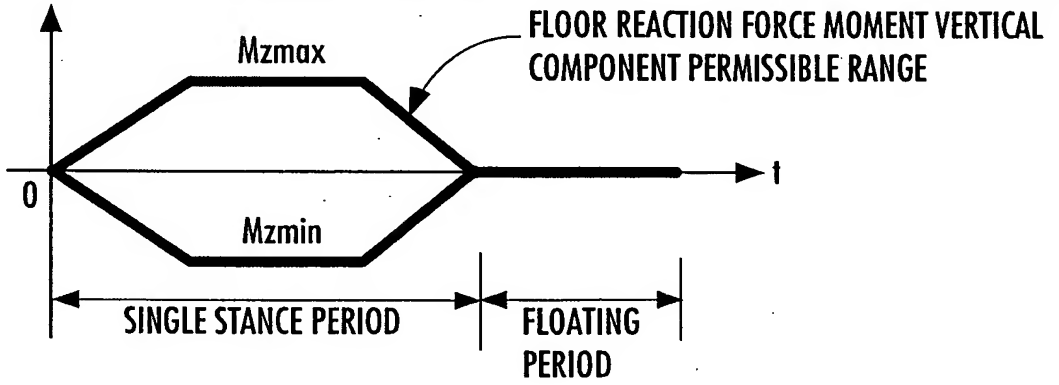


FIG.42

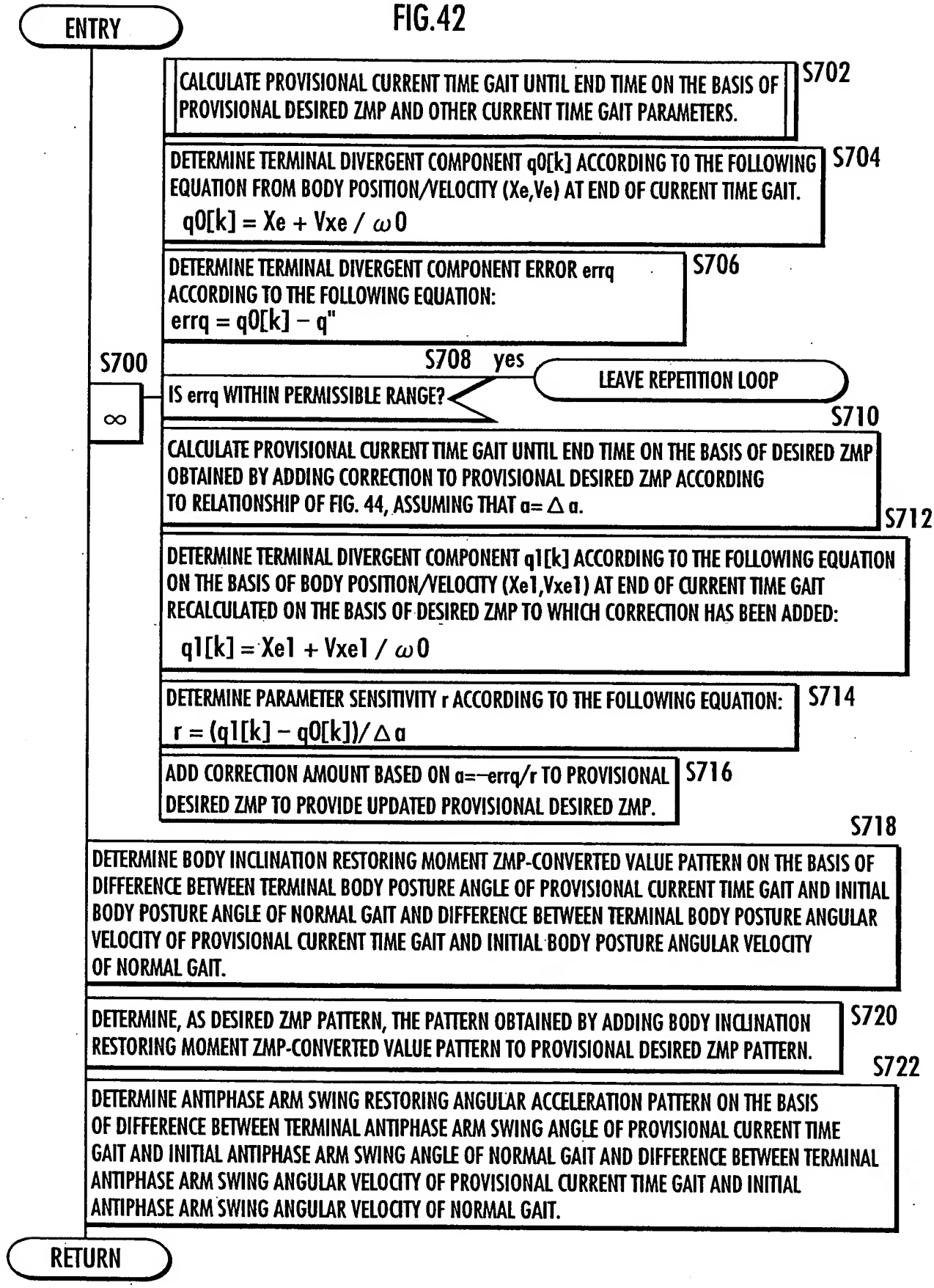

ENTRY
CALCULATE PROVISIONAL CURRENT TIME GAIT UNTIL END TIME ON THE BASIS OF PROVISIONAL DESIRED ZMP AND OTHER CURRENT TIME GAIT PARAMETERS.
S702
DETERMINE TERMINAL DIVERGENT COMPONENT q0[k] ACCORDING TO THE FOLLOWING EQUATION FROM BODY POSITION/VELOCITY (Xe,Ve) AT END OF CURRENT TIME GAIT.
q0[k] = Xe + Vxe / ω0
S704
DETERMINE TERMINAL DIVERGENT COMPONENT ERROR errq ACCORDING TO THE FOLLOWING EQUATION:
errq = q0[k] − q"
S706
S700
∞
S708
yes
IS errq WITHIN PERMISSIBLE RANGE?
LEAVE REPETITION LOOP
S710
CALCULATE PROVISIONAL CURRENT TIME GAIT UNTIL END TIME ON THE BASIS OF DESIRED ZMP OBTAINED BY ADDING CORRECTION TO PROVISIONAL DESIRED ZMP ACCORDING TO RELATIONSHIP OF FIG. 44, ASSUMING THAT α= Δ α.
S712
DETERMINE TERMINAL DIVERGENT COMPONENT q1[k] ACCORDING TO THE FOLLOWING EQUATION ON THE BASIS OF BODY POSITION/VELOCITY (Xe1,Vxe1) AT END OF CURRENT TIME GAIT RECALCULATED ON THE BASIS OF DESIRED ZMP TO WHICH CORRECTION HAS BEEN ADDED:
q1[k] = Xe1 + Vxe1 / ω0
DETERMINE PARAMETER SENSITIVITY r ACCORDING TO THE FOLLOWING EQUATION:
r = (q1[k] − q0[k])/Δα
S714
ADD CORRECTION AMOUNT BASED ON α=−errq/r TO PROVISIONAL DESIRED ZMP TO PROVIDE UPDATED PROVISIONAL DESIRED ZMP.
S716
S718
DETERMINE BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN ON THE BASIS OF DIFFERENCE BETWEEN TERMINAL BODY POSTURE ANGLE OF PROVISIONAL CURRENT TIME GAIT AND INITIAL BODY POSTURE ANGLE OF NORMAL GAIT AND DIFFERENCE BETWEEN TERMINAL BODY POSTURE ANGULAR VELOCITY OF PROVISIONAL CURRENT TIME GAIT AND INITIAL BODY POSTURE ANGULAR VELOCITY OF NORMAL GAIT.
DETERMINE, AS DESIRED ZMP PATTERN, THE PATTERN OBTAINED BY ADDING BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN TO PROVISIONAL DESIRED ZMP PATTERN.
S720
S722
DETERMINE ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN ON THE BASIS OF DIFFERENCE BETWEEN TERMINAL ANTIPHASE ARM SWING ANGLE OF PROVISIONAL CURRENT TIME GAIT AND INITIAL ANTIPHASE ARM SWING ANGLE OF NORMAL GAIT AND DIFFERENCE BETWEEN TERMINAL ANTIPHASE ARM SWING ANGULAR VELOCITY OF PROVISIONAL CURRENT TIME GAIT AND INITIAL ANTIPHASE ARM SWING ANGULAR VELOCITY OF NORMAL GAIT.
RETURN

FIG.43

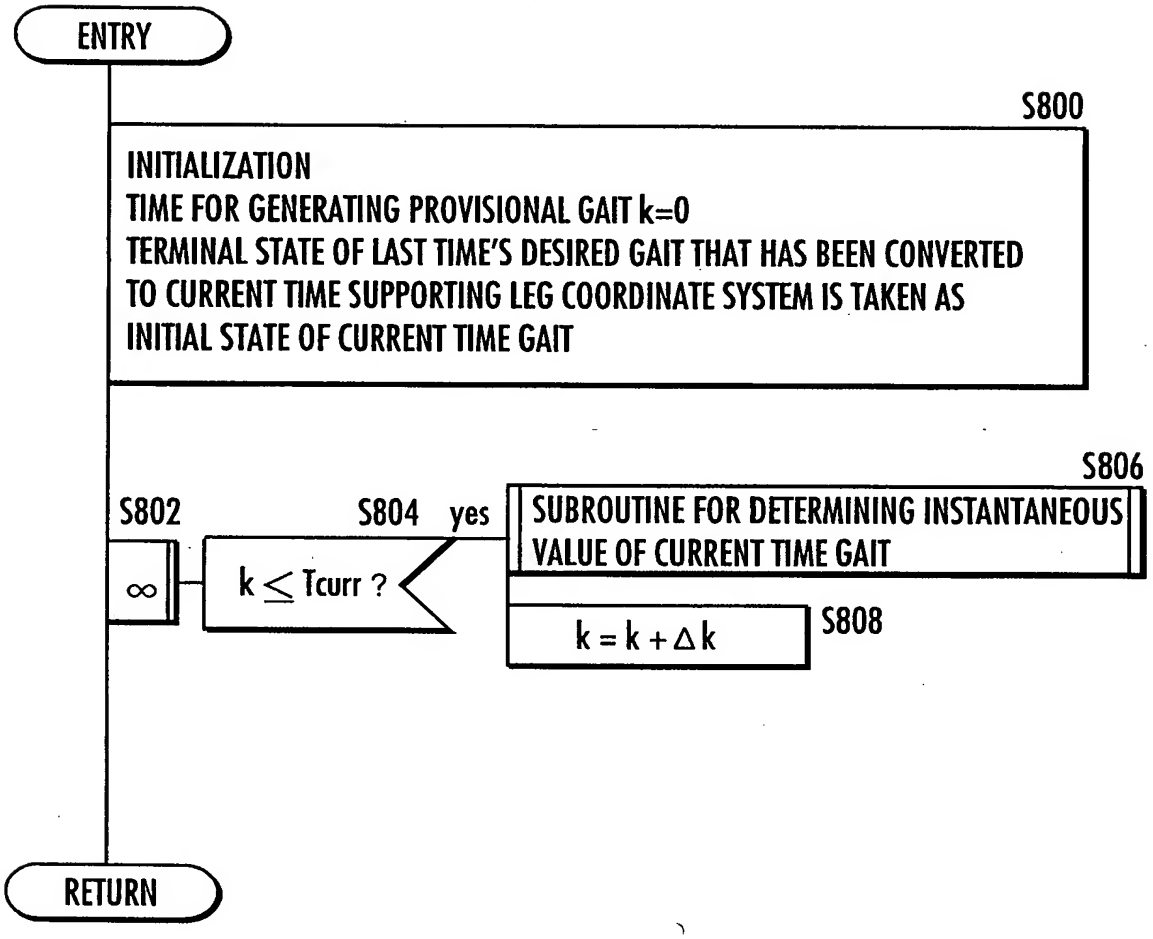

ENTRY
S800
INITIALIZATION
TIME FOR GENERATING PROVISIONAL GAIT k=0
TERMINAL STATE OF LAST TIME'S DESIRED GAIT THAT HAS BEEN CONVERTED TO CURRENT TIME SUPPORTING LEG COORDINATE SYSTEM IS TAKEN AS INITIAL STATE OF CURRENT TIME GAIT
S806
S802
S804
yes
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT
∞
k ≤ Tcurr ?
k = k + Δk
S808
RETURN

FIG.44

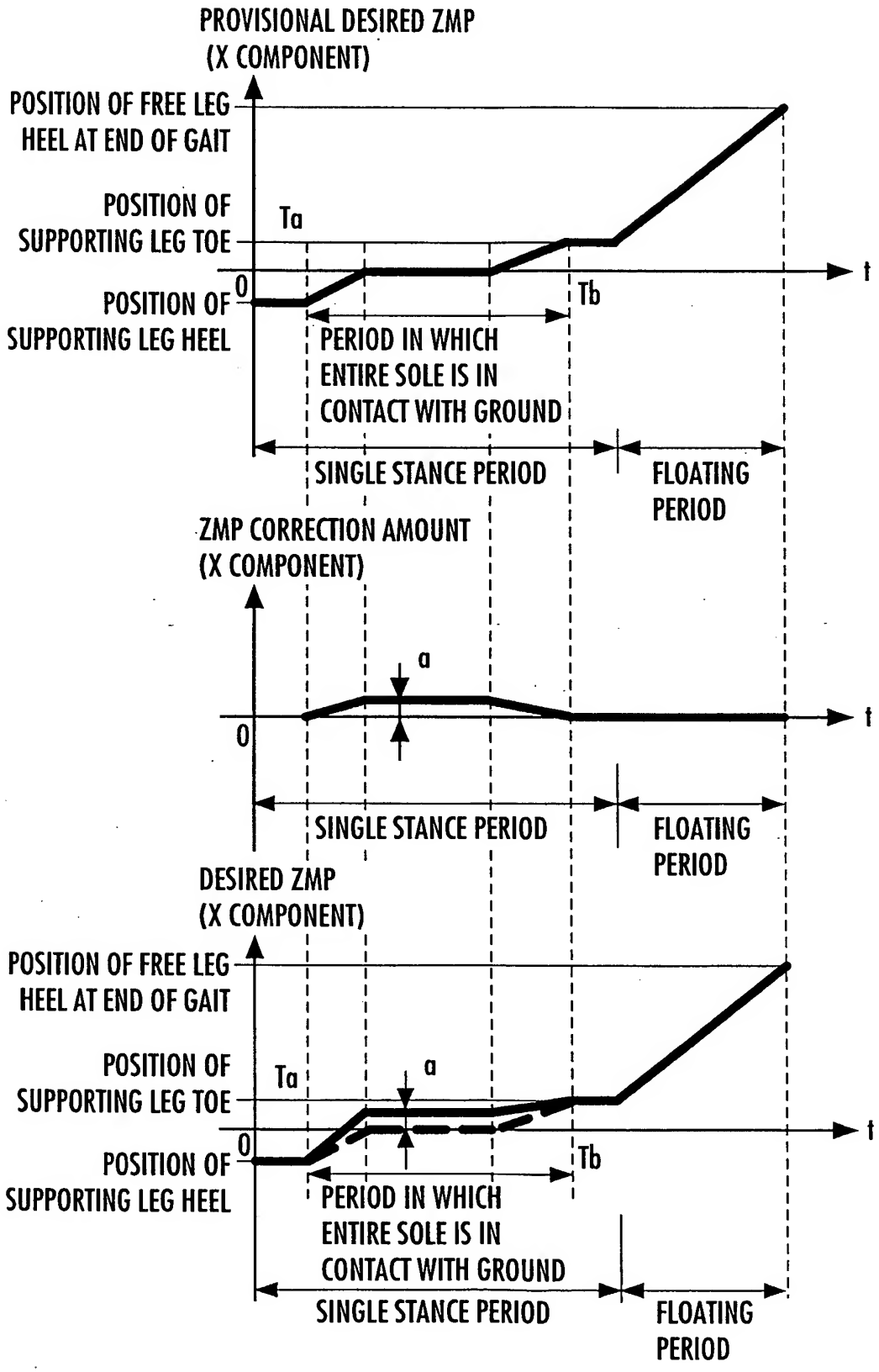

PROVISIONAL DESIRED ZMP
(X COMPONENT)
POSITION OF FREE LEG
HEEL AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
Ta
Tb
0
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD
ZMP CORRECTION AMOUNT
(X COMPONENT)
a
0
t
SINGLE STANCE PERIOD
FLOATING
PERIOD
DESIRED ZMP
(X COMPONENT)
POSITION OF FREE LEG
HEEL AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
Ta
a
0
Tb
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.45

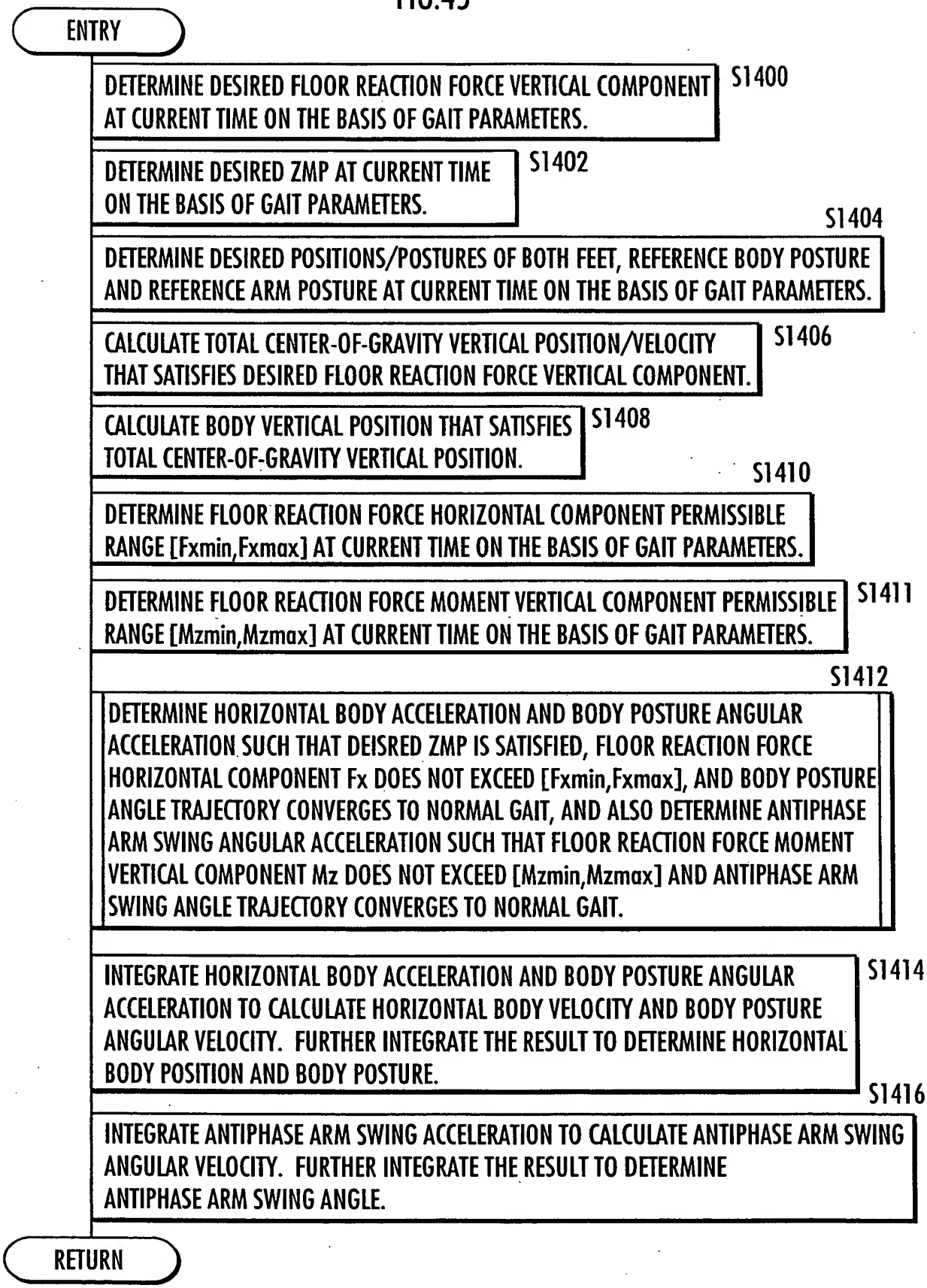

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1400
DETERMINE DESIRED ZMP AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1402
S1404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFIES DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S1406
CALCULATE BODY VERTICAL POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S1408
S1410
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1411
S1412
DETERMINE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT DEISRED ZMP IS SATISFIED, FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin,Fxmax], AND BODY POSTURE ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT, AND ALSO DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz DOES NOT EXCEED [Mzmin,Mzmax] AND ANTIPHASE ARM SWING ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT.
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
S1414
S1416
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
RETURN

FIG.46

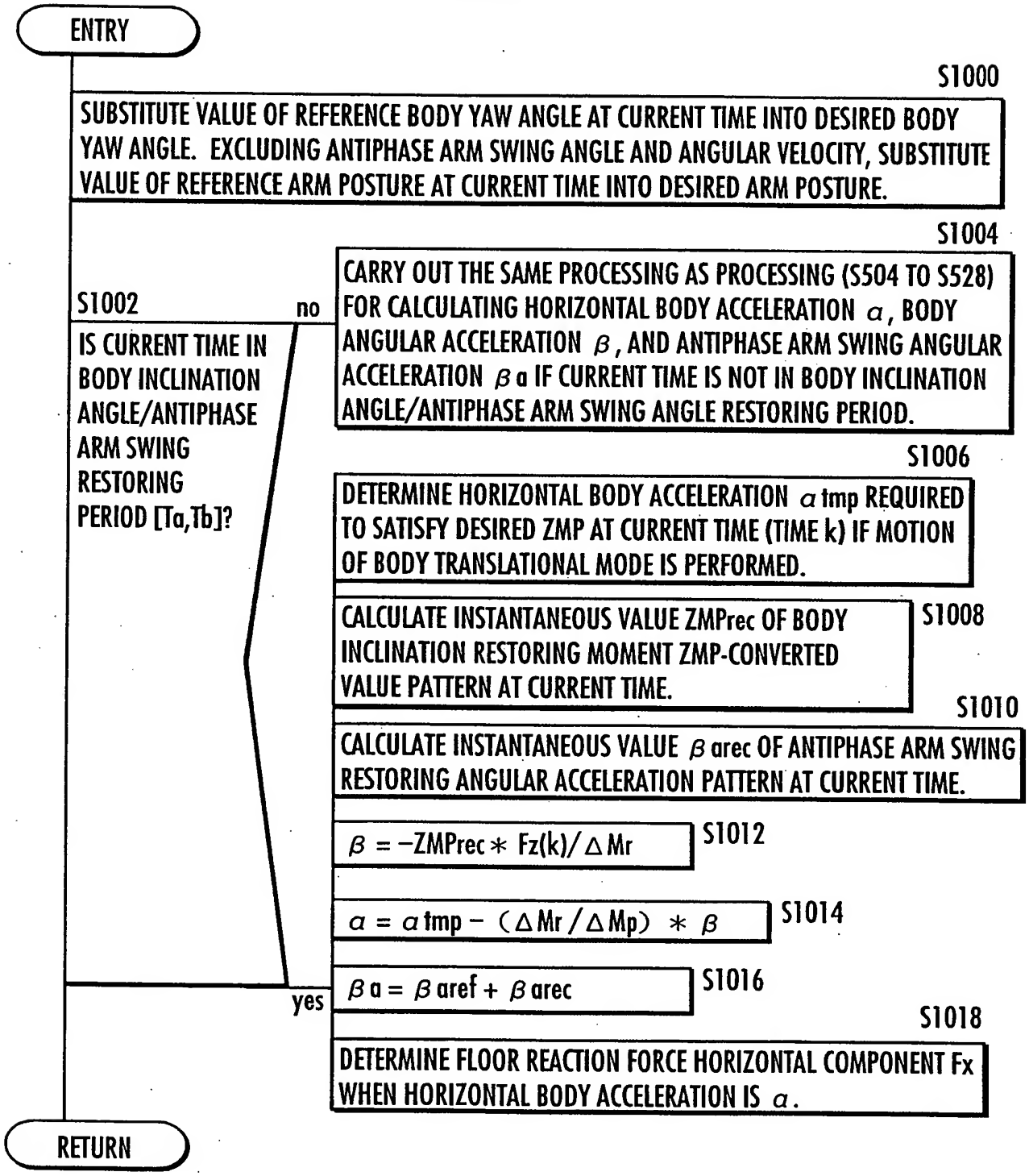

ENTRY
S1000
SUBSTITUTE VALUE OF REFERENCE BODY YAW ANGLE AT CURRENT TIME INTO DESIRED BODY YAW ANGLE. EXCLUDING ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY, SUBSTITUTE VALUE OF REFERENCE ARM POSTURE AT CURRENT TIME INTO DESIRED ARM POSTURE.
S1002
IS CURRENT TIME IN BODY INCLINATION ANGLE/ANTIPHASE ARM SWING RESTORING PERIOD [Ta,Tb]?
no
S1004
CARRY OUT THE SAME PROCESSING AS PROCESSING (S504 TO S528) FOR CALCULATING HORIZONTAL BODY ACCELERATION α, BODY ANGULAR ACCELERATION β, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION βa IF CURRENT TIME IS NOT IN BODY INCLINATION ANGLE/ANTIPHASE ARM SWING ANGLE RESTORING PERIOD.
S1006
DETERMINE HORIZONTAL BODY ACCELERATION α tmp REQUIRED TO SATISFY DESIRED ZMP AT CURRENT TIME (TIME k) IF MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
S1008
CALCULATE INSTANTANEOUS VALUE ZMPrec OF BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN AT CURRENT TIME.
S1010
CALCULATE INSTANTANEOUS VALUE β arec OF ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN AT CURRENT TIME.
β = −ZMPrec * Fz(k)/ΔMr
S1012
α = α tmp − (ΔMr / ΔMp) * β
S1014
yes
βa = β aref + β arec
S1016
S1018
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN HORIZONTAL BODY ACCELERATION IS α.
RETURN

FIG.47

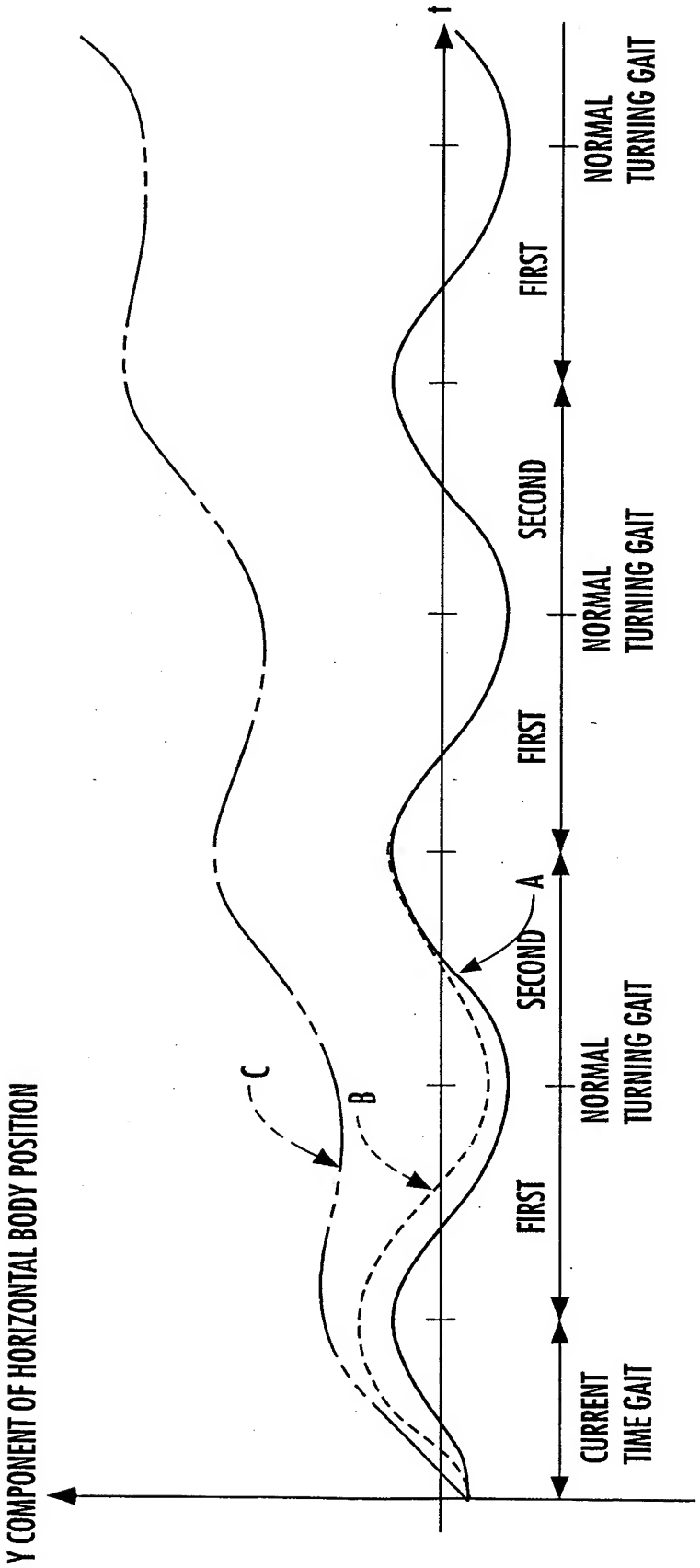

Y COMPONENT OF HORIZONTAL BODY POSITION
t
C
B
A
FIRST
SECOND
FIRST
SECOND
FIRST
CURRENT TIME GAIT
NORMAL TURNING GAIT
NORMAL TURNING GAIT
NORMAL TURNING GAIT

FIG.48

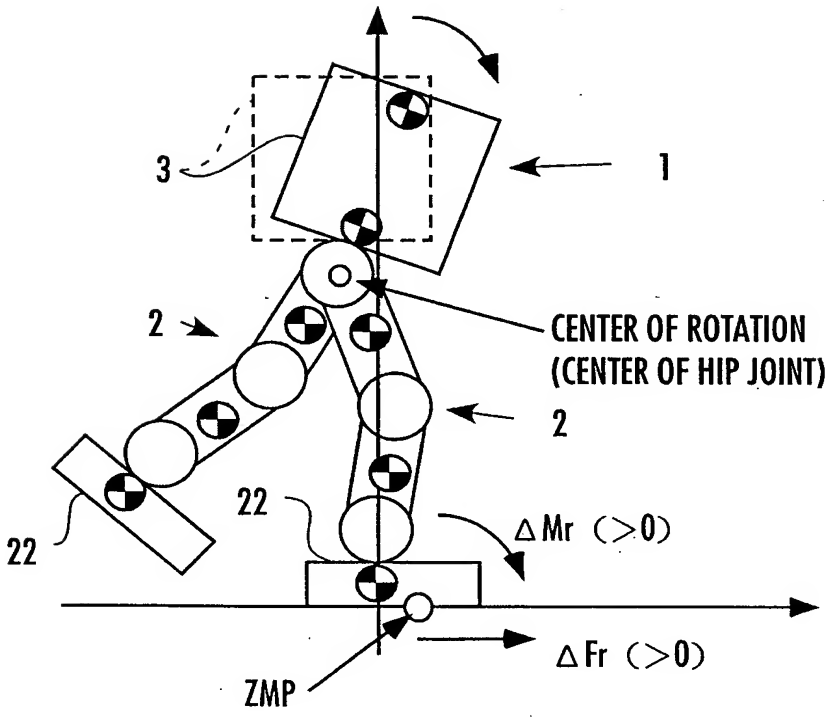

3
1
2
CENTER OF ROTATION
(CENTER OF HIP JOINT)
2
22
22
ΔMr (>0)
ΔFr (>0)
ZMP

FIG.49

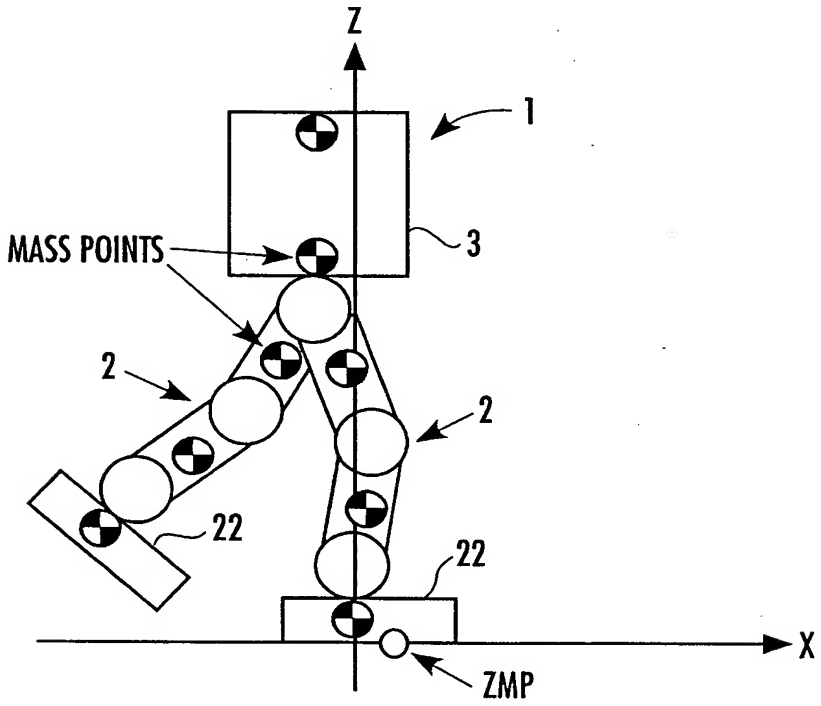


FIG.50

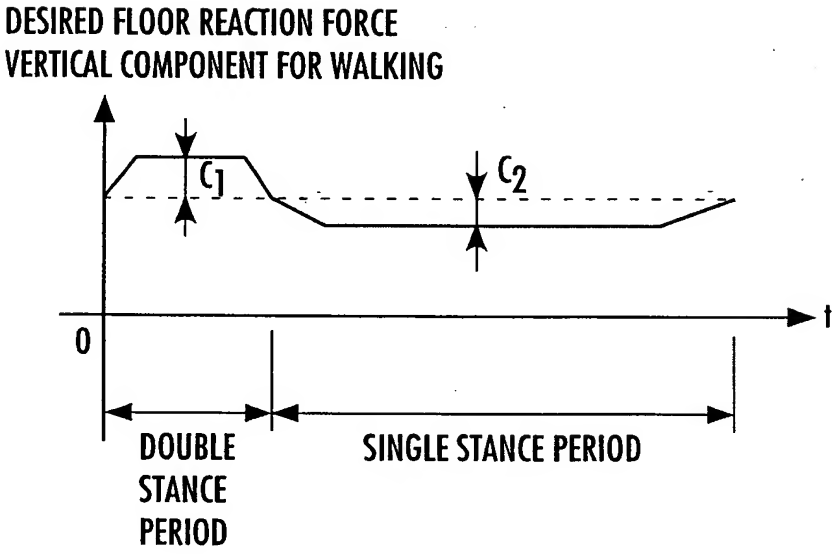

DESIRED FLOOR REACTION FORCE
VERTICAL COMPONENT FOR WALKING
C1
C2
t
0
DOUBLE STANCE PERIOD
SINGLE STANCE PERIOD

FIG.51

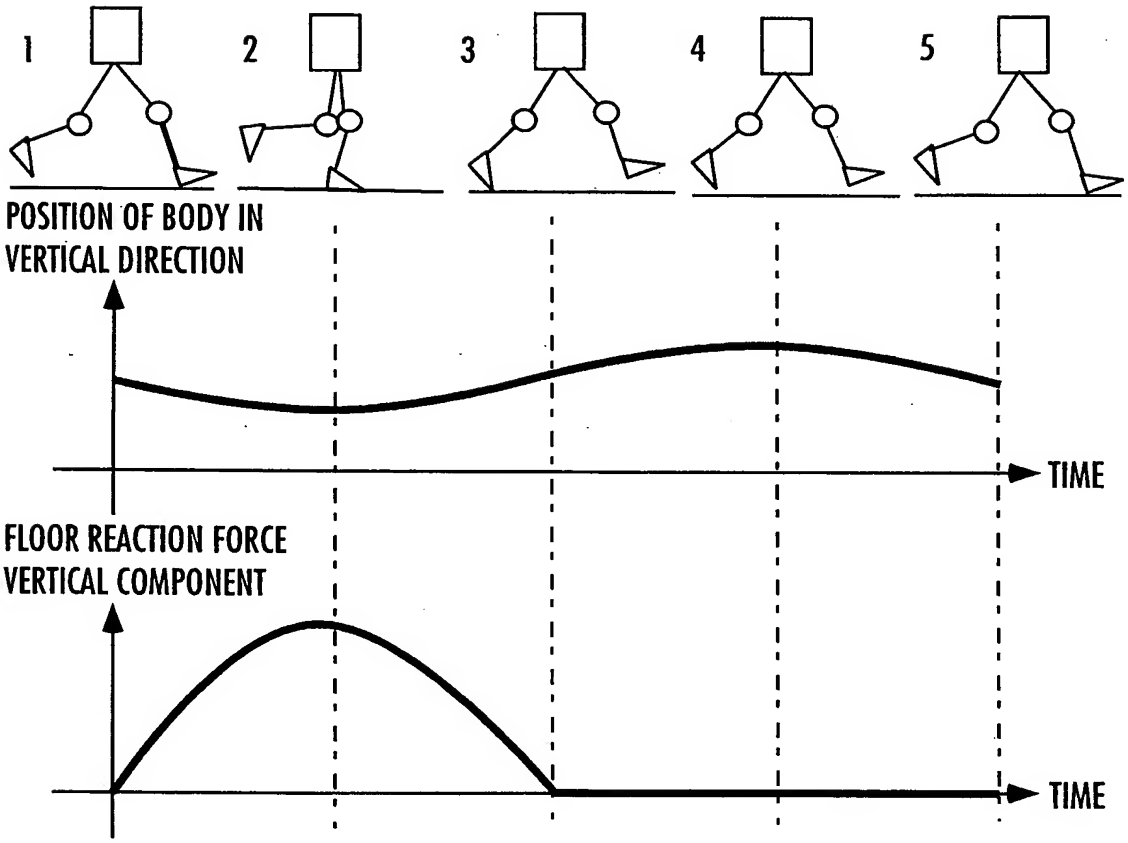

1
2
3
4
5
POSITION OF BODY IN VERTICAL DIRECTION
TIME
FLOOR REACTION FORCE VERTICAL COMPONENT
TIME

FIG.52

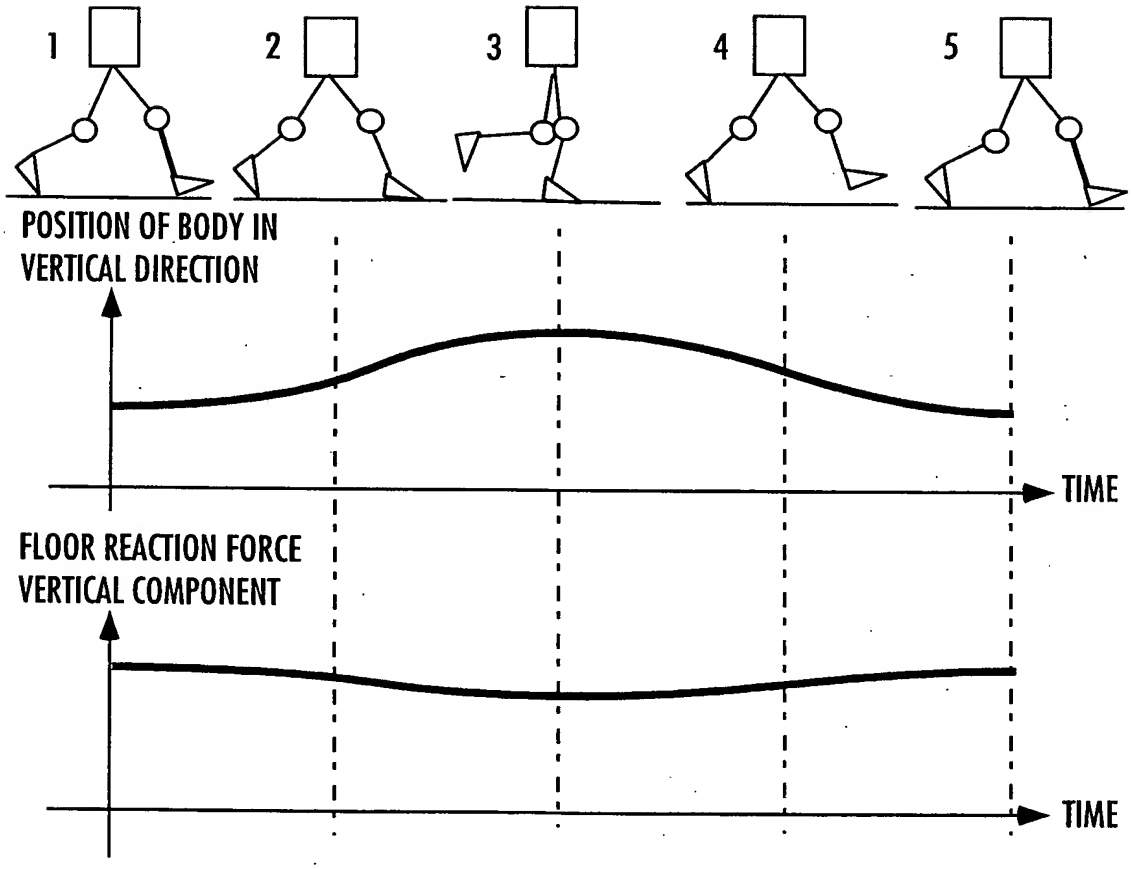

1
2
3
4
5
POSITION OF BODY IN VERTICAL DIRECTION
TIME
FLOOR REACTION FORCE VERTICAL COMPONENT
TIME

FIG.53

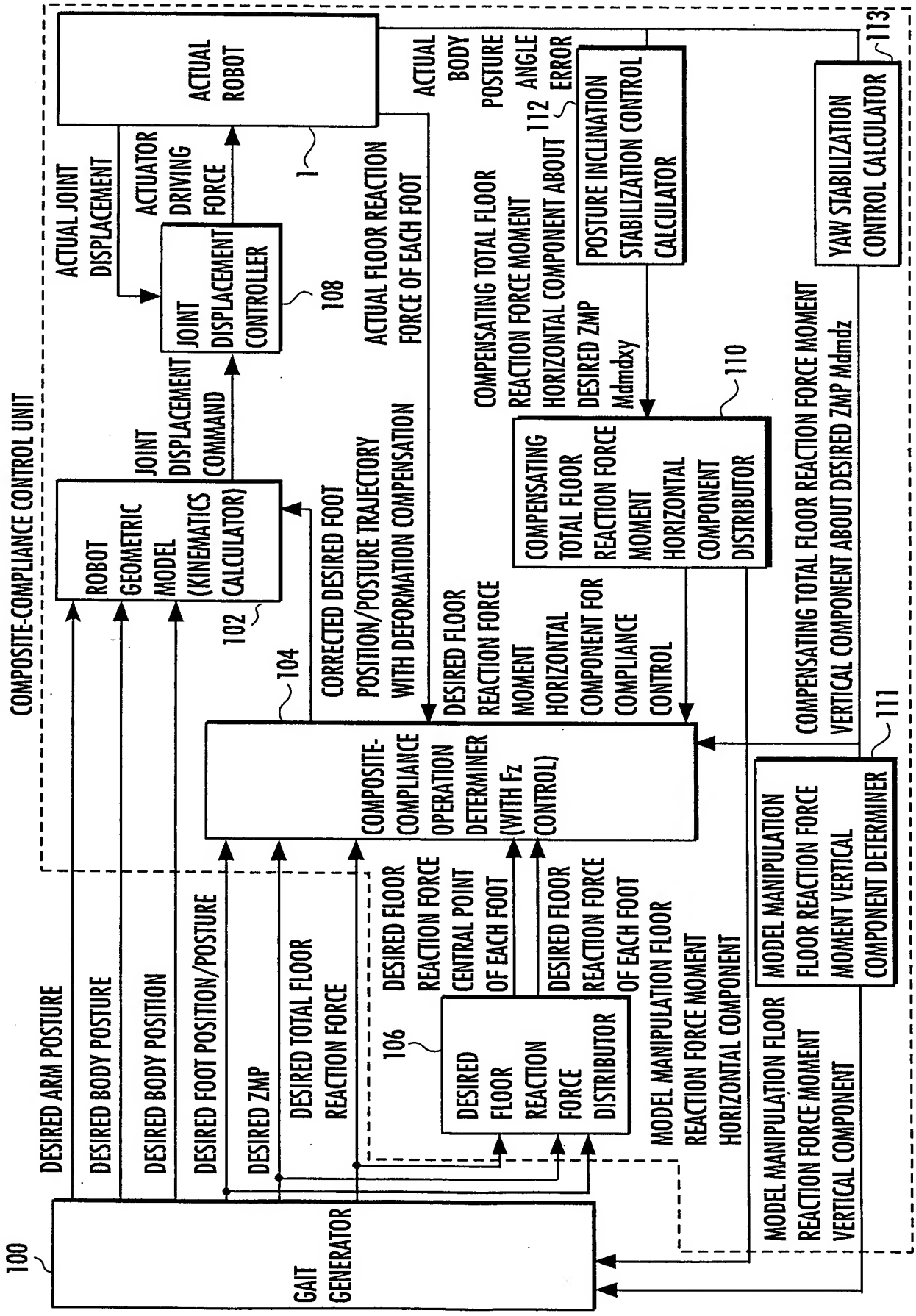

COMPOSITE-COMPLIANCE CONTROL UNIT
GAIT GENERATOR
100
DESIRED ARM POSTURE
DESIRED BODY POSTURE
DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
106
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT DETERMINER
111
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT ABOUT DESIRED ZMP Mdmdz
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
104
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT DISTRIBUTOR
110
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP Mdmdxy
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
102
JOINT DISPLACEMENT COMMAND
JOINT DISPLACEMENT CONTROLLER
108
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
ACTUAL ROBOT
1
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
ACTUAL BODY POSTURE ANGLE ERROR
112
POSTURE INCLINATION STABILIZATION CONTROL CALCULATOR
YAW STABILIZATION CONTROL CALCULATOR
113

FIG.54

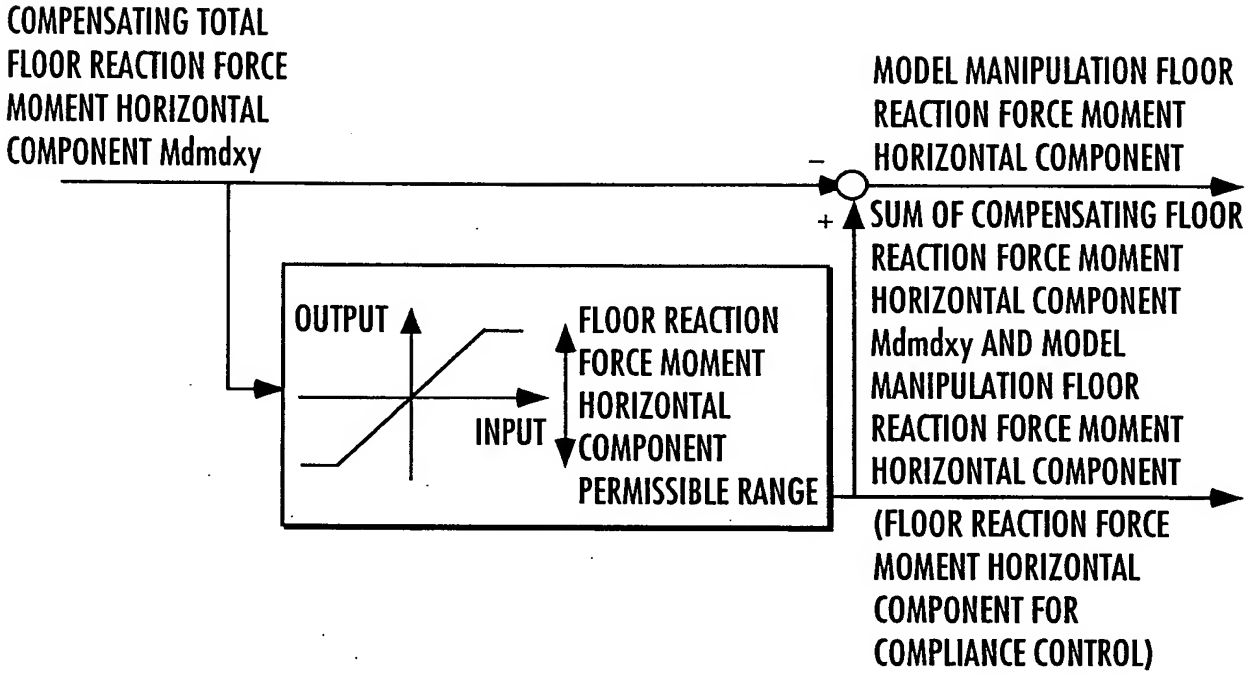

COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
–
+
SUM OF COMPENSATING FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy AND MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
OUTPUT
INPUT
FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE
(FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL)

FIG.55

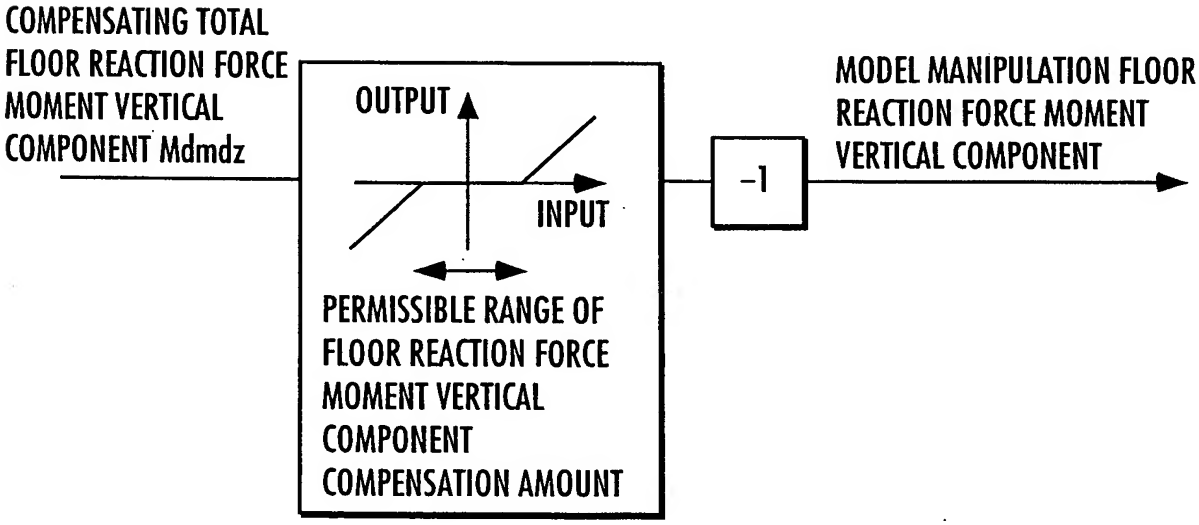

COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz
OUTPUT
INPUT
PERMISSIBLE RANGE OF FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT COMPENSATION AMOUNT
-1
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT

FIG.56

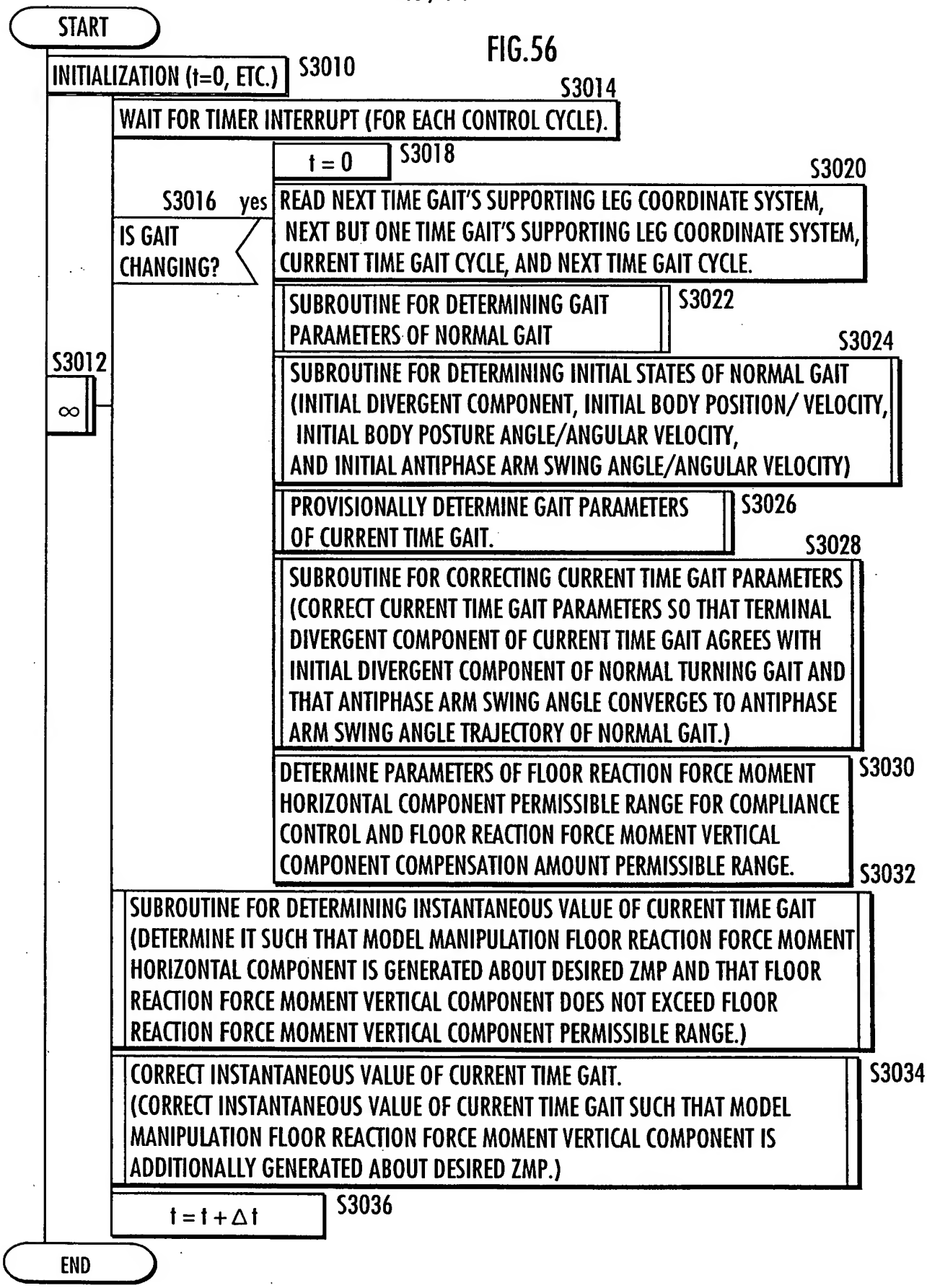

START
INITIALIZATION (t=0, ETC.)
S3010
S3014
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
t = 0
S3018
S3020
S3016
yes
IS GAIT CHANGING?
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S3022
S3024
S3012
∞
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S3026
S3028
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
DETERMINE PARAMETERS OF FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR COMPLIANCE CONTROL AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT COMPENSATION AMOUNT PERMISSIBLE RANGE.
S3030
S3032
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT (DETERMINE IT SUCH THAT MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT IS GENERATED ABOUT DESIRED ZMP AND THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT DOES NOT EXCEED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE.)
CORRECT INSTANTANEOUS VALUE OF CURRENT TIME GAIT. (CORRECT INSTANTANEOUS VALUE OF CURRENT TIME GAIT SUCH THAT MODEL MANIPULATION FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT IS ADDITIONALLY GENERATED ABOUT DESIRED ZMP.)
S3034
t = t + Δt
S3036
END

FIG.57

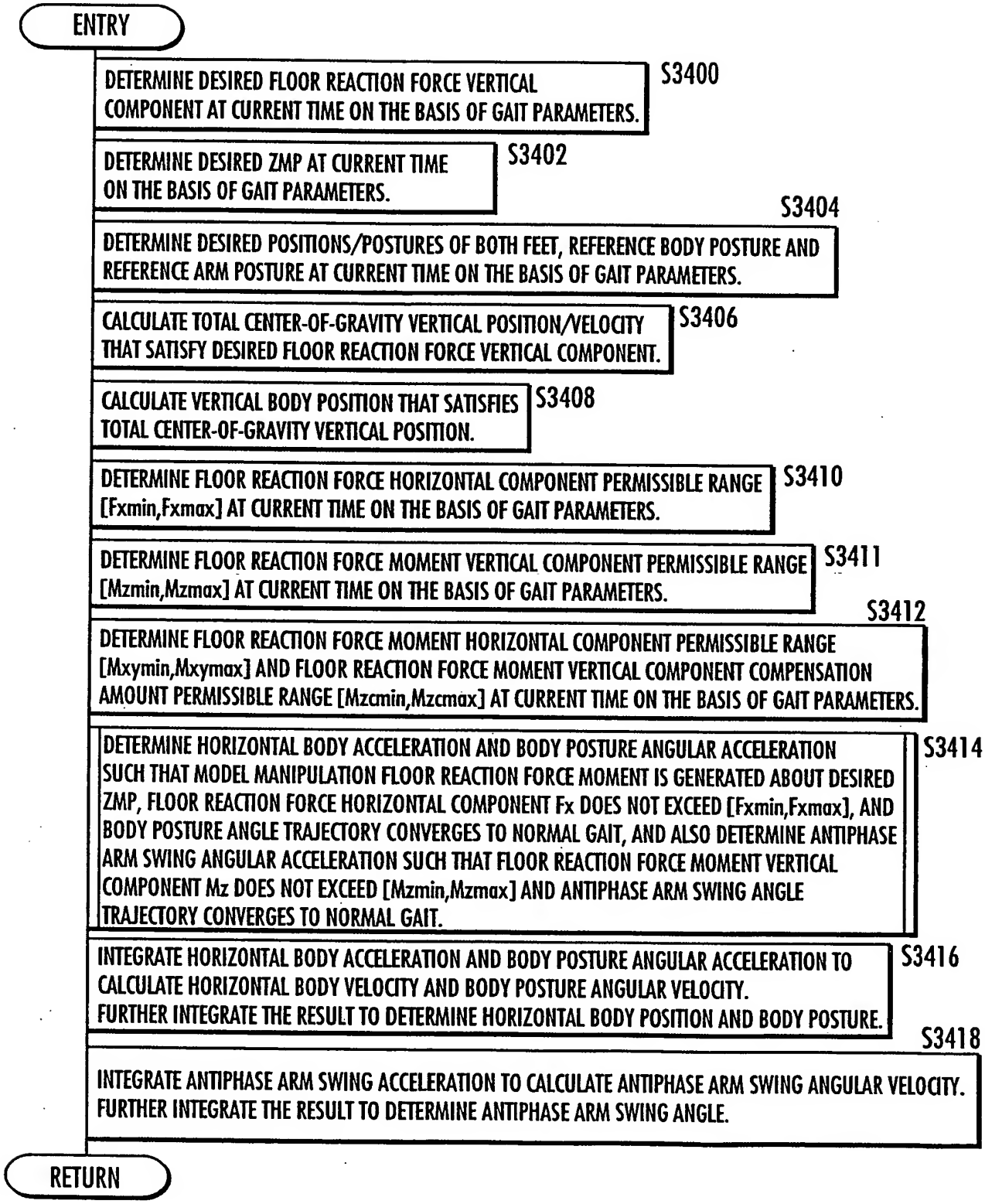

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S3400
DETERMINE DESIRED ZMP AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S3402
S3404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S3406
CALCULATE VERTICAL BODY POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S3408
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S3410
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S3411
S3412
DETERMINE FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE [Mxymin,Mxymax] AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT COMPENSATION AMOUNT PERMISSIBLE RANGE [Mzcmin,Mzcmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
DETERMINE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT MODEL MANIPULATION FLOOR REACTION FORCE MOMENT IS GENERATED ABOUT DESIRED ZMP, FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin,Fxmax], AND BODY POSTURE ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT, AND ALSO DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz DOES NOT EXCEED [Mzmin,Mzmax] AND ANTIPHASE ARM SWING ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT.
S3414
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
S3416
S3418
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
RETURN

FIG.58

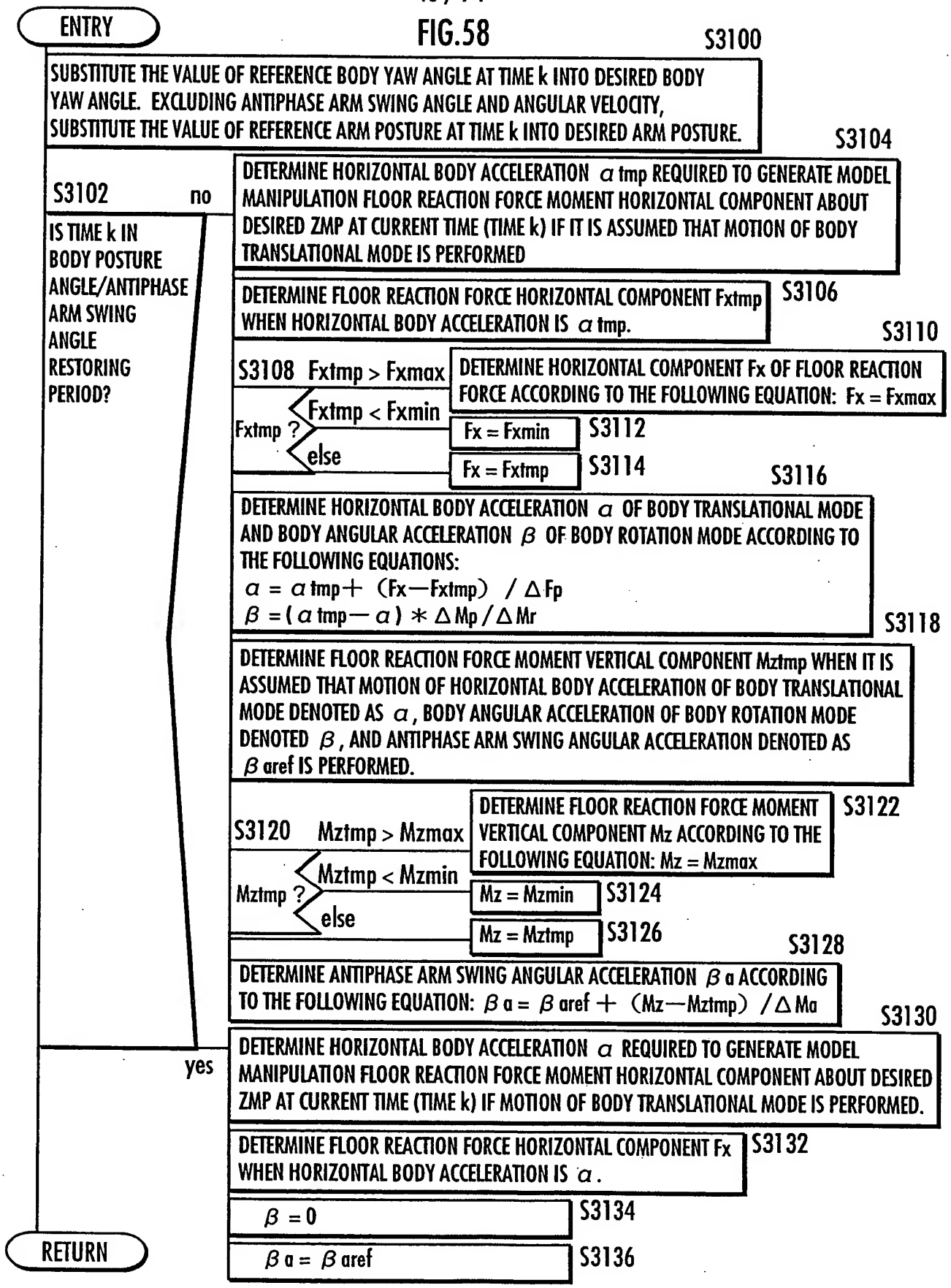

ENTRY
S3100
SUBSTITUTE THE VALUE OF REFERENCE BODY YAW ANGLE AT TIME k INTO DESIRED BODY YAW ANGLE. EXCLUDING ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY, SUBSTITUTE THE VALUE OF REFERENCE ARM POSTURE AT TIME k INTO DESIRED ARM POSTURE.
S3102
IS TIME k IN BODY POSTURE ANGLE/ANTIPHASE ARM SWING ANGLE RESTORING PERIOD?
no
S3104
DETERMINE HORIZONTAL BODY ACCELERATION α tmp REQUIRED TO GENERATE MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP AT CURRENT TIME (TIME k) IF IT IS ASSUMED THAT MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED
S3106
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp WHEN HORIZONTAL BODY ACCELERATION IS α tmp.
S3108 Fxtmp > Fxmax
S3110
DETERMINE HORIZONTAL COMPONENT Fx OF FLOOR REACTION FORCE ACCORDING TO THE FOLLOWING EQUATION: Fx = Fxmax
Fxtmp ?
Fxtmp < Fxmin
Fx = Fxmin
S3112
else
Fx = Fxtmp
S3114
S3116
DETERMINE HORIZONTAL BODY ACCELERATION α OF BODY TRANSLATIONAL MODE AND BODY ANGULAR ACCELERATION β OF BODY ROTATION MODE ACCORDING TO THE FOLLOWING EQUATIONS:
α = α tmp + (Fx − Fxtmp) / ΔFp
β = (α tmp − α) * ΔMp / ΔMr
S3118
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mztmp WHEN IT IS ASSUMED THAT MOTION OF HORIZONTAL BODY ACCELERATION OF BODY TRANSLATIONAL MODE DENOTED AS α, BODY ANGULAR ACCELERATION OF BODY ROTATION MODE DENOTED β, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION DENOTED AS β aref IS PERFORMED.
S3120 Mztmp > Mzmax
S3122
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz ACCORDING TO THE FOLLOWING EQUATION: Mz = Mzmax
Mztmp ?
Mztmp < Mzmin
Mz = Mzmin
S3124
else
Mz = Mztmp
S3126
S3128
DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION β a ACCORDING TO THE FOLLOWING EQUATION: β a = β aref + (Mz − Mztmp) / ΔMa
S3130
yes
DETERMINE HORIZONTAL BODY ACCELERATION α REQUIRED TO GENERATE MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP AT CURRENT TIME (TIME k) IF MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN HORIZONTAL BODY ACCELERATION IS α.
S3132
β = 0
S3134
β a = β aref
S3136
RETURN

FIG.59

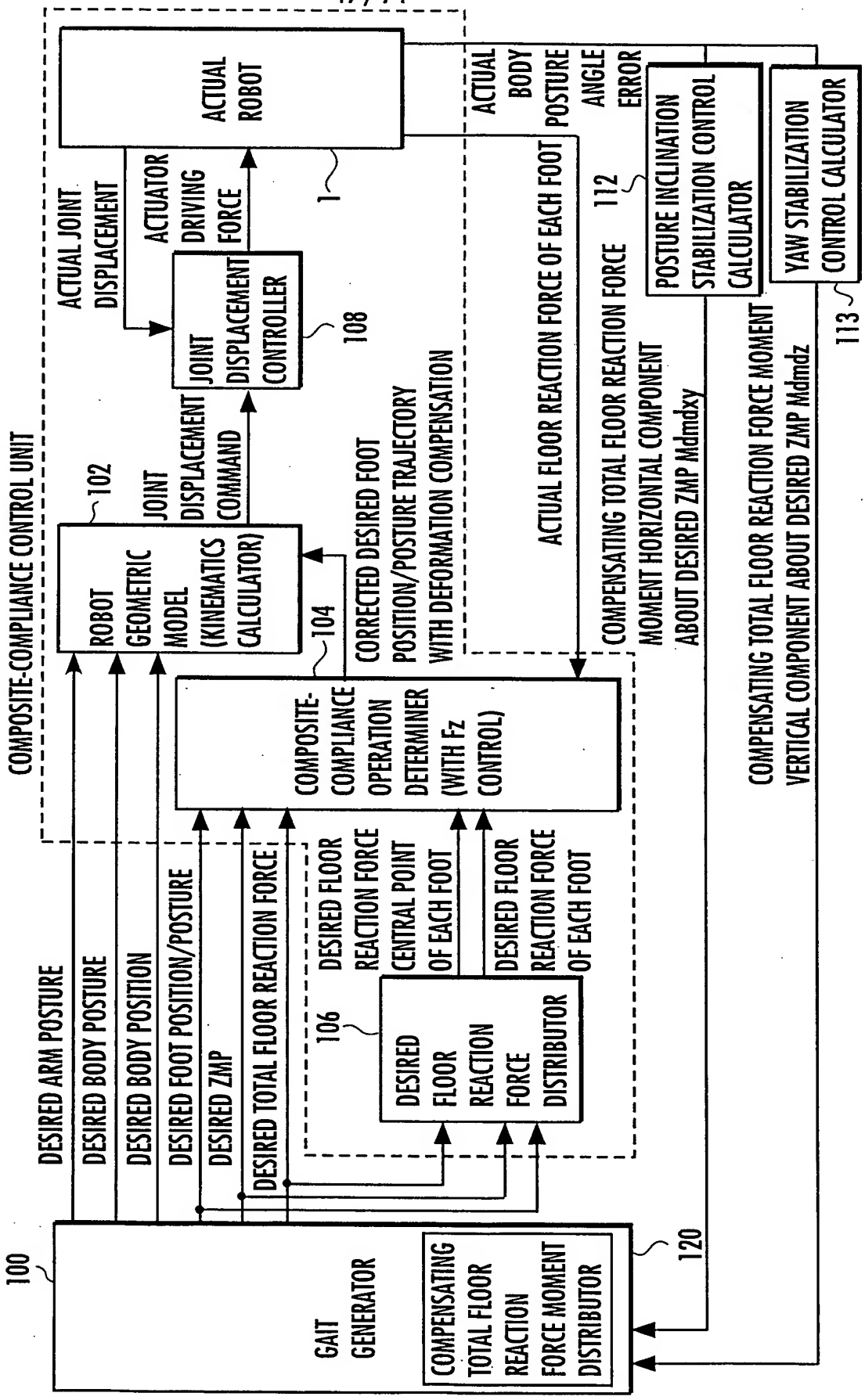

COMPOSITE-COMPLIANCE CONTROL UNIT
ACTUAL ROBOT
1
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
JOINT DISPLACEMENT CONTROLLER
108
ACTUAL BODY POSTURE ANGLE ERROR
POSTURE INCLINATION STABILIZATION CONTROL CALCULATOR
112
YAW STABILIZATION CONTROL CALCULATOR
113
102
JOINT DISPLACEMENT COMMAND
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
104
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP Mdmdxy
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT ABOUT DESIRED ZMP Mdmdz
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
DESIRED ARM POSTURE
DESIRED BODY POSTURE
DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
106
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
100
GAIT GENERATOR
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
120

FIG.60

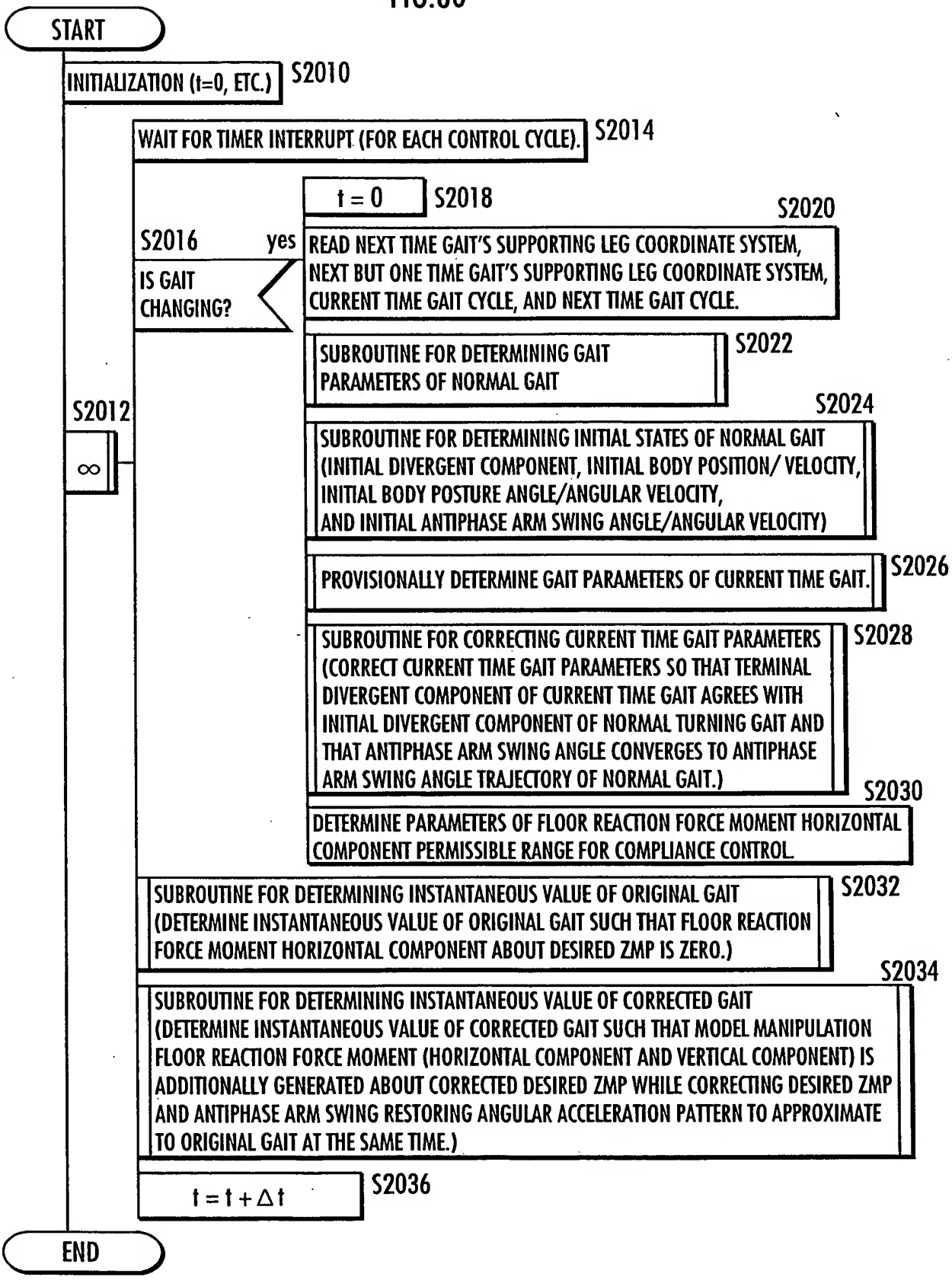

START
INITIALIZATION (t=0, ETC.)
S2010
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S2014
t = 0
S2018
S2016
yes
IS GAIT CHANGING?
S2020
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S2022
S2012
∞
S2024
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S2026
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
S2028
S2030
DETERMINE PARAMETERS OF FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR COMPLIANCE CONTROL
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF ORIGINAL GAIT (DETERMINE INSTANTANEOUS VALUE OF ORIGINAL GAIT SUCH THAT FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP IS ZERO.)
S2032
S2034
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CORRECTED GAIT (DETERMINE INSTANTANEOUS VALUE OF CORRECTED GAIT SUCH THAT MODEL MANIPULATION FLOOR REACTION FORCE MOMENT (HORIZONTAL COMPONENT AND VERTICAL COMPONENT) IS ADDITIONALLY GENERATED ABOUT CORRECTED DESIRED ZMP WHILE CORRECTING DESIRED ZMP AND ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN TO APPROXIMATE TO ORIGINAL GAIT AT THE SAME TIME.)
t = t + Δt
S2036
END

FIG.61

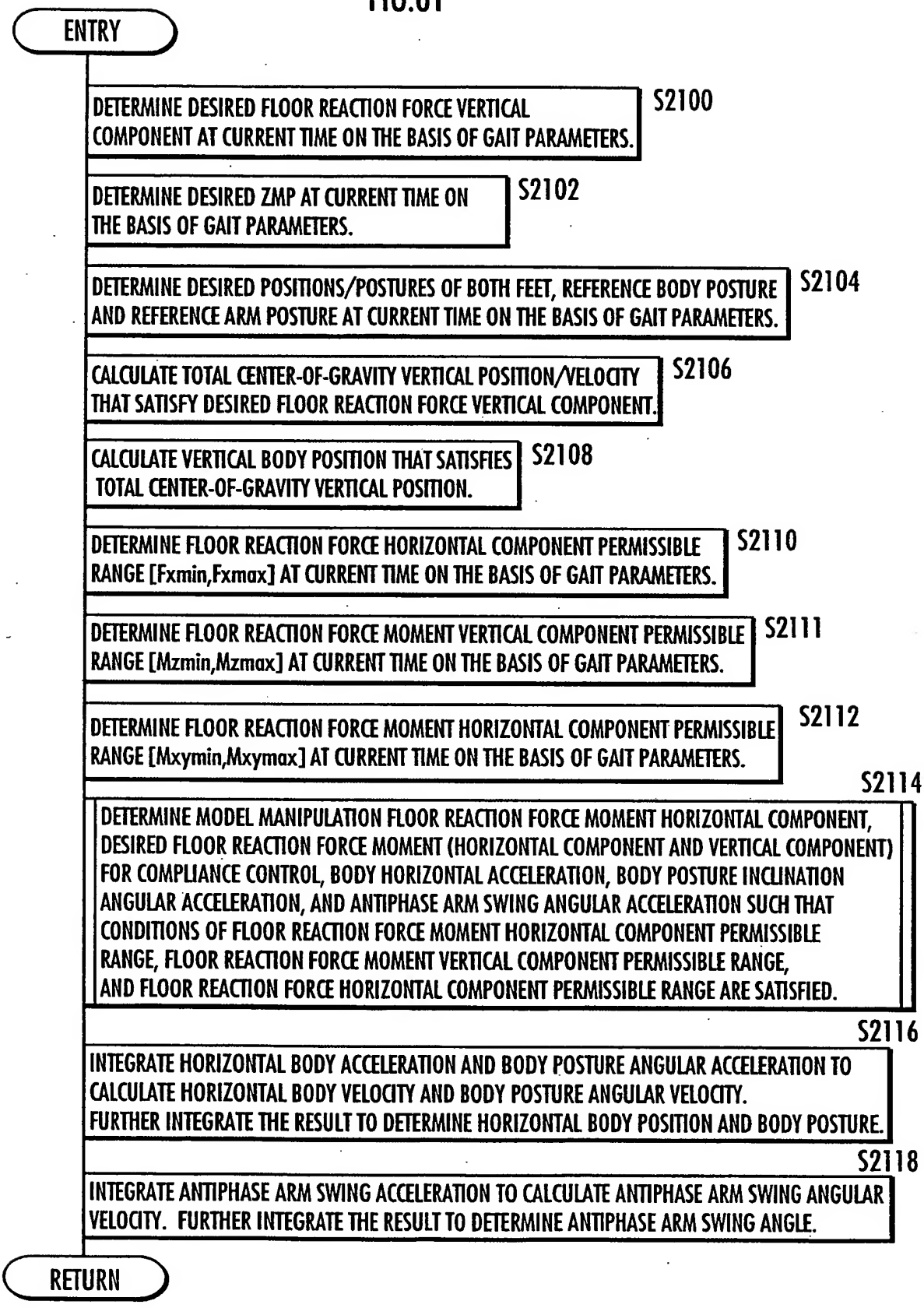

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2100
DETERMINE DESIRED ZMP AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2102
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2104
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S2106
CALCULATE VERTICAL BODY POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S2108
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2110
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2111
DETERMINE FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE [Mxymin,Mxymax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S2112
DETERMINE MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT, DESIRED FLOOR REACTION FORCE MOMENT (HORIZONTAL COMPONENT AND VERTICAL COMPONENT) FOR COMPLIANCE CONTROL, BODY HORIZONTAL ACCELERATION, BODY POSTURE INCLINATION ANGULAR ACCELERATION, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT CONDITIONS OF FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE, FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE, AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE ARE SATISFIED.
S2114
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
S2116
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
S2118
RETURN

FIG.62

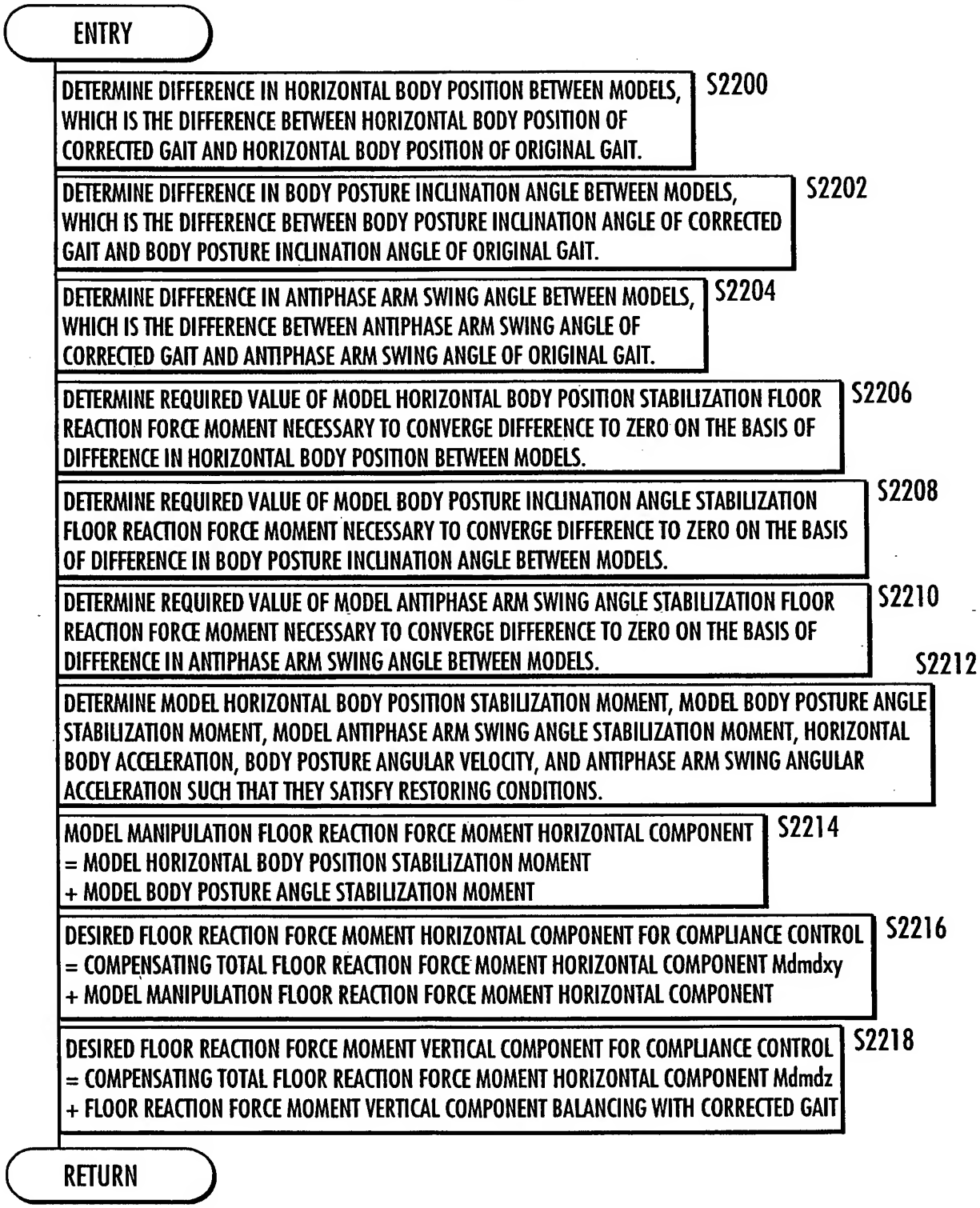

ENTRY
DETERMINE DIFFERENCE IN HORIZONTAL BODY POSITION BETWEEN MODELS, WHICH IS THE DIFFERENCE BETWEEN HORIZONTAL BODY POSITION OF CORRECTED GAIT AND HORIZONTAL BODY POSITION OF ORIGINAL GAIT.
S2200
DETERMINE DIFFERENCE IN BODY POSTURE INCLINATION ANGLE BETWEEN MODELS, WHICH IS THE DIFFERENCE BETWEEN BODY POSTURE INCLINATION ANGLE OF CORRECTED GAIT AND BODY POSTURE INCLINATION ANGLE OF ORIGINAL GAIT.
S2202
DETERMINE DIFFERENCE IN ANTIPHASE ARM SWING ANGLE BETWEEN MODELS, WHICH IS THE DIFFERENCE BETWEEN ANTIPHASE ARM SWING ANGLE OF CORRECTED GAIT AND ANTIPHASE ARM SWING ANGLE OF ORIGINAL GAIT.
S2204
DETERMINE REQUIRED VALUE OF MODEL HORIZONTAL BODY POSITION STABILIZATION FLOOR REACTION FORCE MOMENT NECESSARY TO CONVERGE DIFFERENCE TO ZERO ON THE BASIS OF DIFFERENCE IN HORIZONTAL BODY POSITION BETWEEN MODELS.
S2206
DETERMINE REQUIRED VALUE OF MODEL BODY POSTURE INCLINATION ANGLE STABILIZATION FLOOR REACTION FORCE MOMENT NECESSARY TO CONVERGE DIFFERENCE TO ZERO ON THE BASIS OF DIFFERENCE IN BODY POSTURE INCLINATION ANGLE BETWEEN MODELS.
S2208
DETERMINE REQUIRED VALUE OF MODEL ANTIPHASE ARM SWING ANGLE STABILIZATION FLOOR REACTION FORCE MOMENT NECESSARY TO CONVERGE DIFFERENCE TO ZERO ON THE BASIS OF DIFFERENCE IN ANTIPHASE ARM SWING ANGLE BETWEEN MODELS.
S2210
DETERMINE MODEL HORIZONTAL BODY POSITION STABILIZATION MOMENT, MODEL BODY POSTURE ANGLE STABILIZATION MOMENT, MODEL ANTIPHASE ARM SWING ANGLE STABILIZATION MOMENT, HORIZONTAL BODY ACCELERATION, BODY POSTURE ANGULAR VELOCITY, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT THEY SATISFY RESTORING CONDITIONS.
S2212
MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
= MODEL HORIZONTAL BODY POSITION STABILIZATION MOMENT
+ MODEL BODY POSTURE ANGLE STABILIZATION MOMENT
S2214
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
= COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
+ MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
S2216
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL
= COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdz
+ FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT BALANCING WITH CORRECTED GAIT
S2218
RETURN

FIG.63

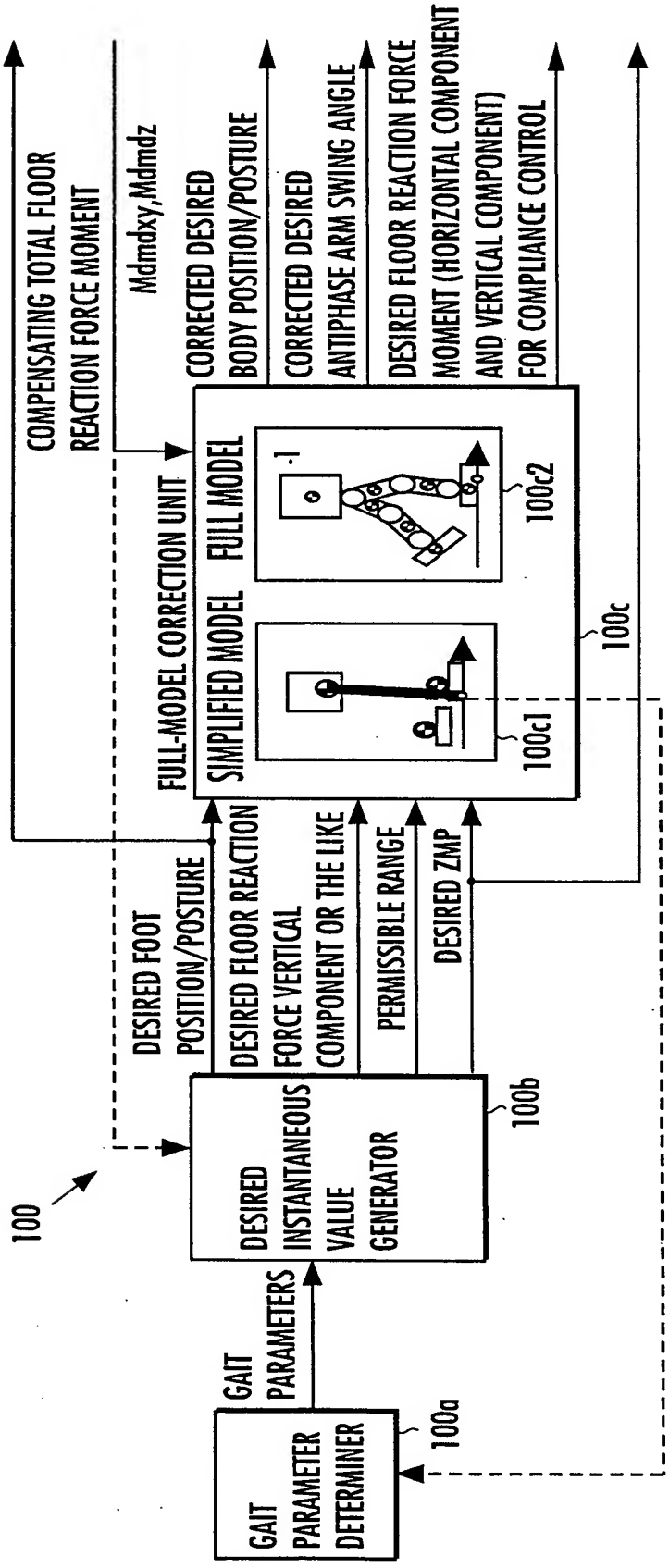

100
GAIT PARAMETER DETERMINER
100a
GAIT PARAMETERS
DESIRED INSTANTANEOUS VALUE GENERATOR
100b
DESIRED FOOT POSITION/POSTURE
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT OR THE LIKE
PERMISSIBLE RANGE
DESIRED ZMP
FULL-MODEL CORRECTION UNIT
SIMPLIFIED MODEL
FULL MODEL
100c1
100c2
100c
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT
Mdmdxy,Mdmdz
CORRECTED DESIRED BODY POSITION/POSTURE
CORRECTED DESIRED ANTIPHASE ARM SWING ANGLE
DESIRED FLOOR REACTION FORCE MOMENT (HORIZONTAL COMPONENT AND VERTICAL COMPONENT) FOR COMPLIANCE CONTROL

FIG.64

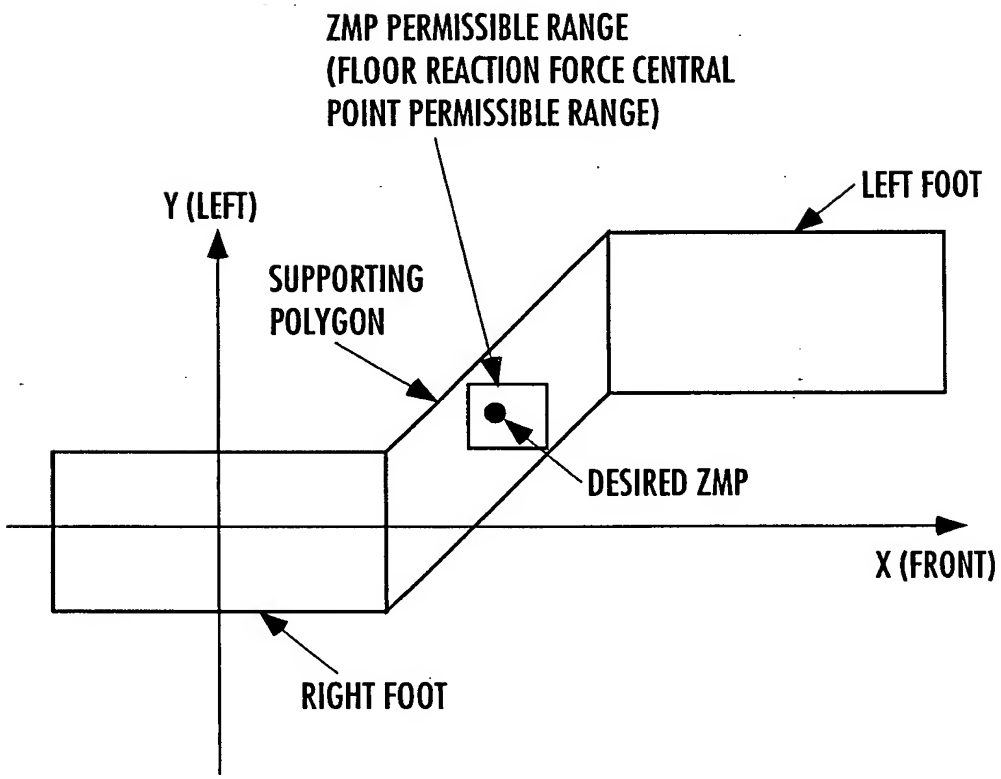

ZMP PERMISSIBLE RANGE
(FLOOR REACTION FORCE CENTRAL
POINT PERMISSIBLE RANGE)
LEFT FOOT
Y (LEFT)
SUPPORTING
POLYGON
DESIRED ZMP
X (FRONT)
RIGHT FOOT

FIG.65

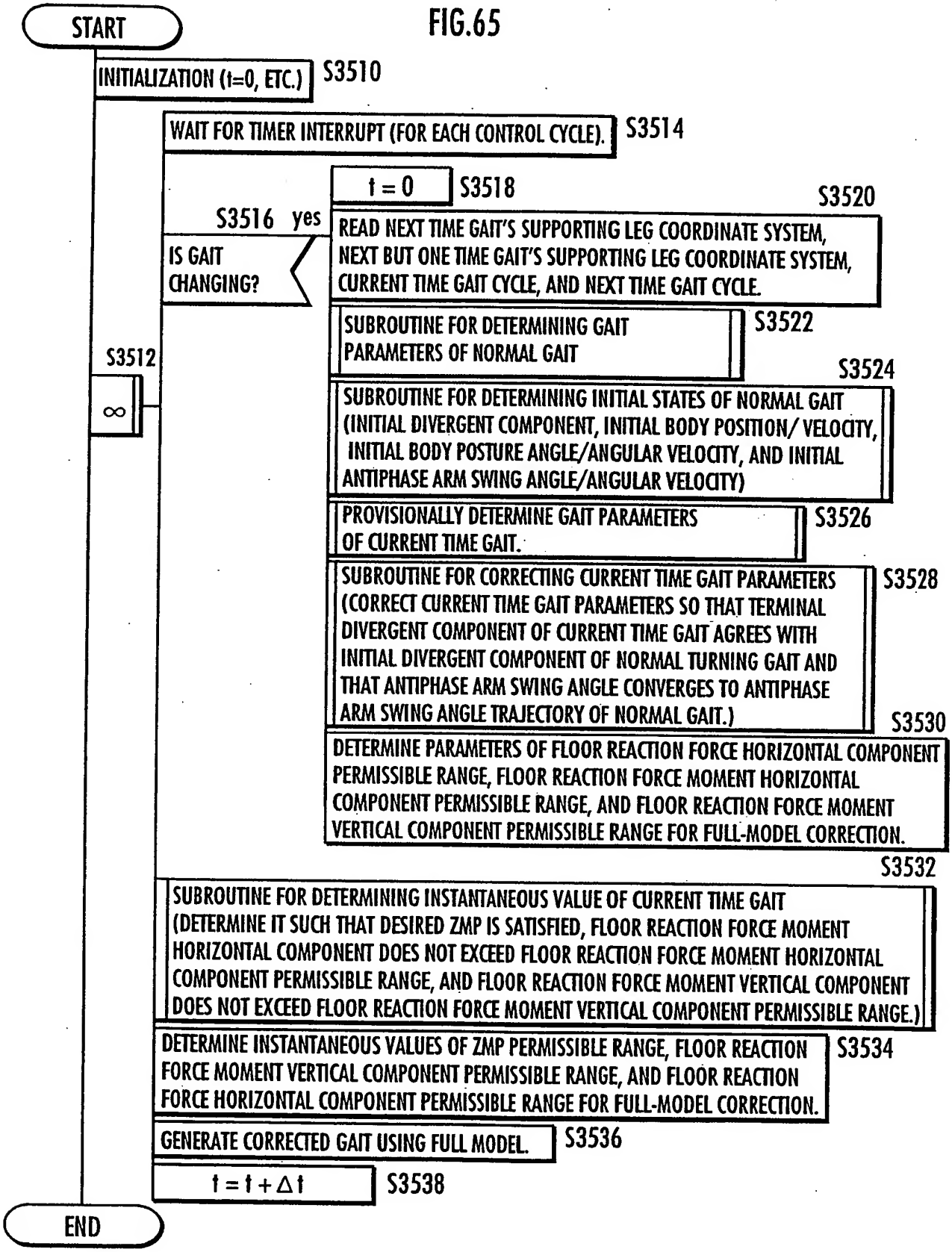

START
INITIALIZATION (t=0, ETC.)
S3510
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S3514
t = 0
S3518
S3516
yes
IS GAIT CHANGING?
S3520
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S3522
S3512
∞
S3524
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S3526
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
S3528
S3530
DETERMINE PARAMETERS OF FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE, FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE, AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE FOR FULL-MODEL CORRECTION.
S3532
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT (DETERMINE IT SUCH THAT DESIRED ZMP IS SATISFIED, FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT DOES NOT EXCEED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE, AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT DOES NOT EXCEED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE.)
DETERMINE INSTANTANEOUS VALUES OF ZMP PERMISSIBLE RANGE, FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE, AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR FULL-MODEL CORRECTION.
S3534
GENERATE CORRECTED GAIT USING FULL MODEL.
S3536
t = t + Δt
S3538
END

FIG.66

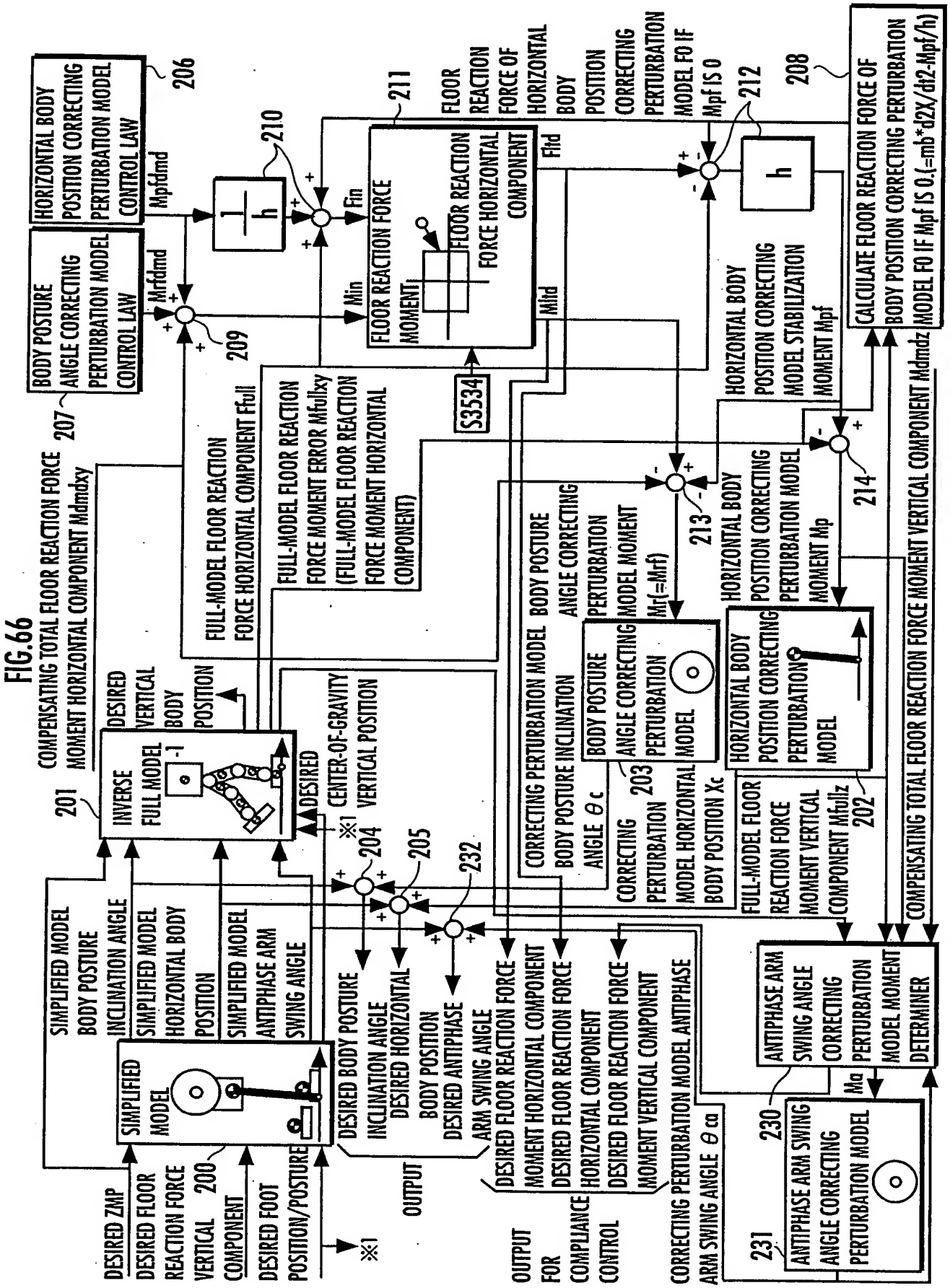

DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
DESIRED FOOT POSITION/POSTURE
※1
200
SIMPLIFIED MODEL
SIMPLIFIED MODEL BODY POSTURE INCLINATION ANGLE
SIMPLIFIED MODEL HORIZONTAL BODY POSITION
SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE
DESIRED BODY POSTURE INCLINATION ANGLE
DESIRED HORIZONTAL BODY POSITION
DESIRED ANTIPHASE ARM SWING ANGLE
OUTPUT
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT
OUTPUT FOR COMPLIANCE CONTROL
CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θ ca
231
230
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL MOMENT DETERMINER
Ma
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz
CALCULATE FLOOR REACTION FORCE OF BODY POSITION CORRECTING PERTURBATION MODEL F0 IF Mpf IS 0.(=mb*d2X/dt2-Mpf/h)
208
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL F0 IF Mpf IS 0
FLOOR REACTION FORCE OF HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL F0 IF Mpf IS 0
212
h
211
FLOOR REACTION FORCE HORIZONTAL COMPONENT
FLOOR REACTION FORCE MOMENT
Fltd
Mltd
Fin
Min
1/h
210
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL STABILIZATION MOMENT Mpf
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL MOMENT Mp
214
213
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
202
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL MOMENT Mr(=Mrf)
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL
CORRECTING PERTURBATION MODEL BODY POSTURE INCLINATION ANGLE θc
CORRECTING PERTURBATION MODEL HORIZONTAL BODY POSITION Xc
203
FULL-MODEL FLOOR REACTION FORCE MOMENT ERROR Mfullxy (FULL-MODEL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT)
FULL-MODEL FLOOR REACTION FORCE HORIZONTAL COMPONENT Ffull
S3534
209
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
Mrfdmd
207
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL CONTROL LAW
Mpfdmd
206
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
DESIRED VERTICAL BODY POSITION
DESIRED CENTER-OF-GRAVITY VERTICAL POSITION
※1
INVERSE FULL MODEL -1
201
204
205
232

FIG.67

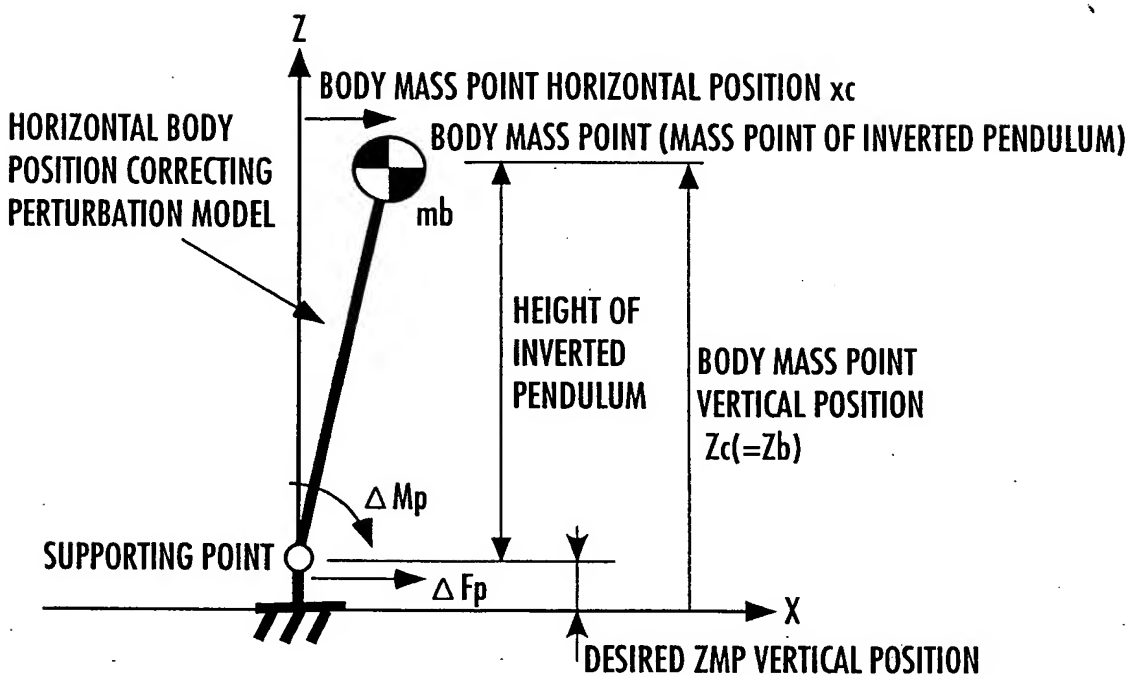

Z
BODY MASS POINT HORIZONTAL POSITION xc
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL
BODY MASS POINT (MASS POINT OF INVERTED PENDULUM)
mb
HEIGHT OF INVERTED PENDULUM
BODY MASS POINT VERTICAL POSITION Zc(=Zb)
Δ Mp
SUPPORTING POINT
Δ Fp
X
DESIRED ZMP VERTICAL POSITION

FIG.68

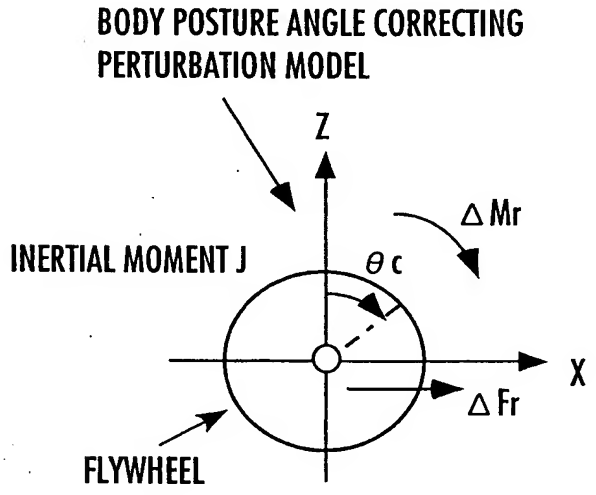

BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL
Z
Δ Mr
INERTIAL MOMENT J
θ c
X
Δ Fr
FLYWHEEL

FIG.69

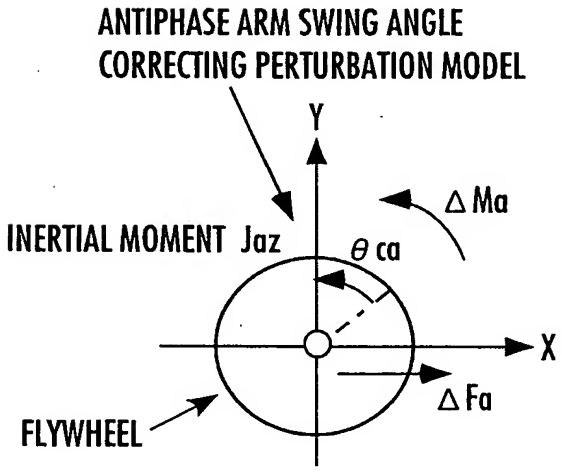

ANTIPHASE ARM SWING ANGLE
CORRECTING PERTURBATION MODEL
Y
ΔMa
INERTIAL MOMENT Jaz
θca
X
ΔFa
FLYWHEEL

FIG.70

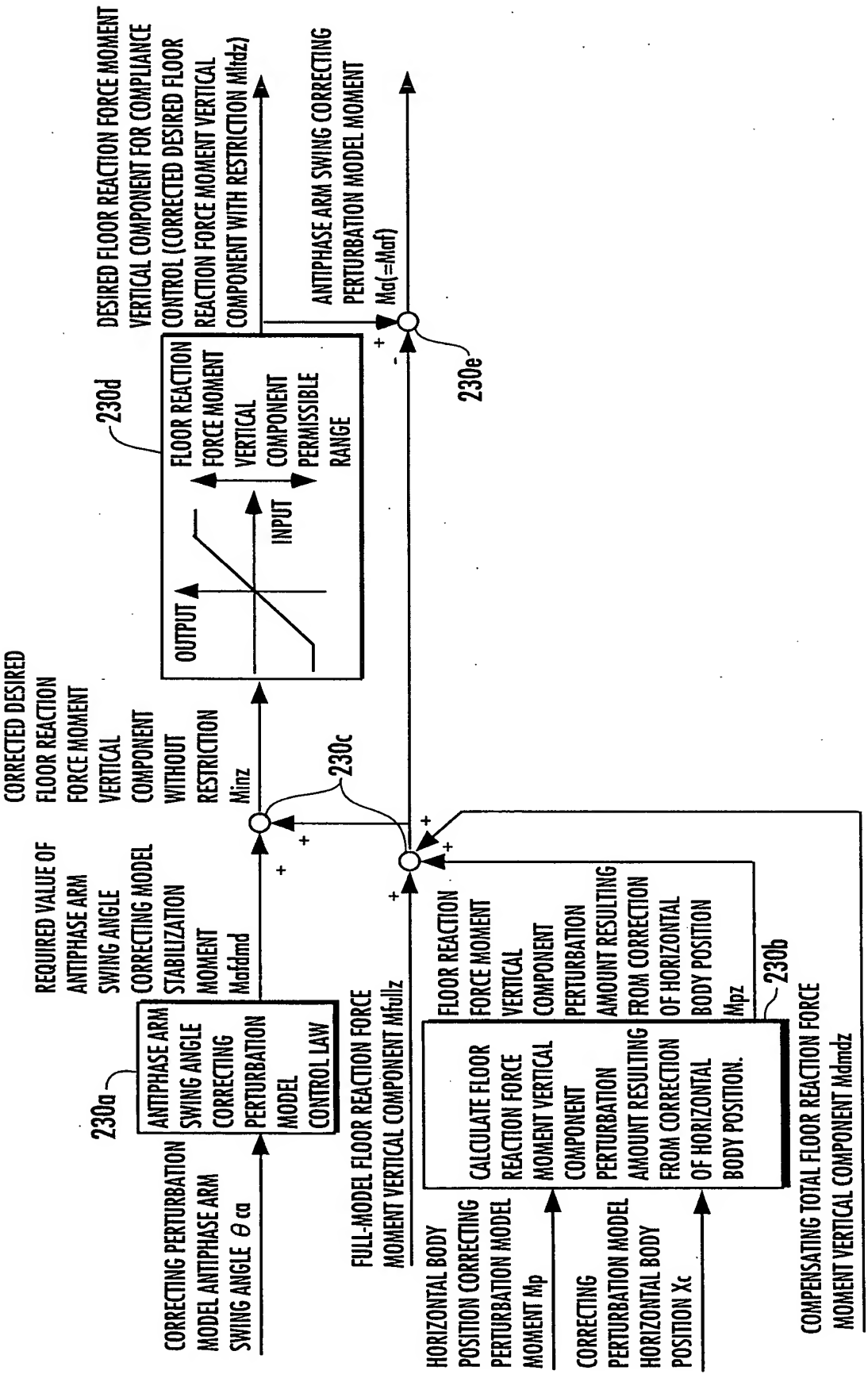

CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θ cα
230a
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
REQUIRED VALUE OF ANTIPHASE ARM SWING ANGLE CORRECTING MODEL STABILIZATION MOMENT Mαfdmd
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITHOUT RESTRICTION Mimz
230c
230d
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE
OUTPUT
INPUT
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL (CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITH RESTRICTION Mfrdz)
ANTIPHASE ARM SWING CORRECTING PERTURBATION MODEL MOMENT Mα(=Mαf)
230e
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL MOMENT Mp
CALCULATE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERTURBATION AMOUNT RESULTING FROM CORRECTION OF HORIZONTAL BODY POSITION.
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERTURBATION AMOUNT RESULTING FROM CORRECTION OF HORIZONTAL BODY POSITION Mpz
230b
CORRECTING PERTURBATION MODEL HORIZONTAL BODY POSITION Xc
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz

FIG.71

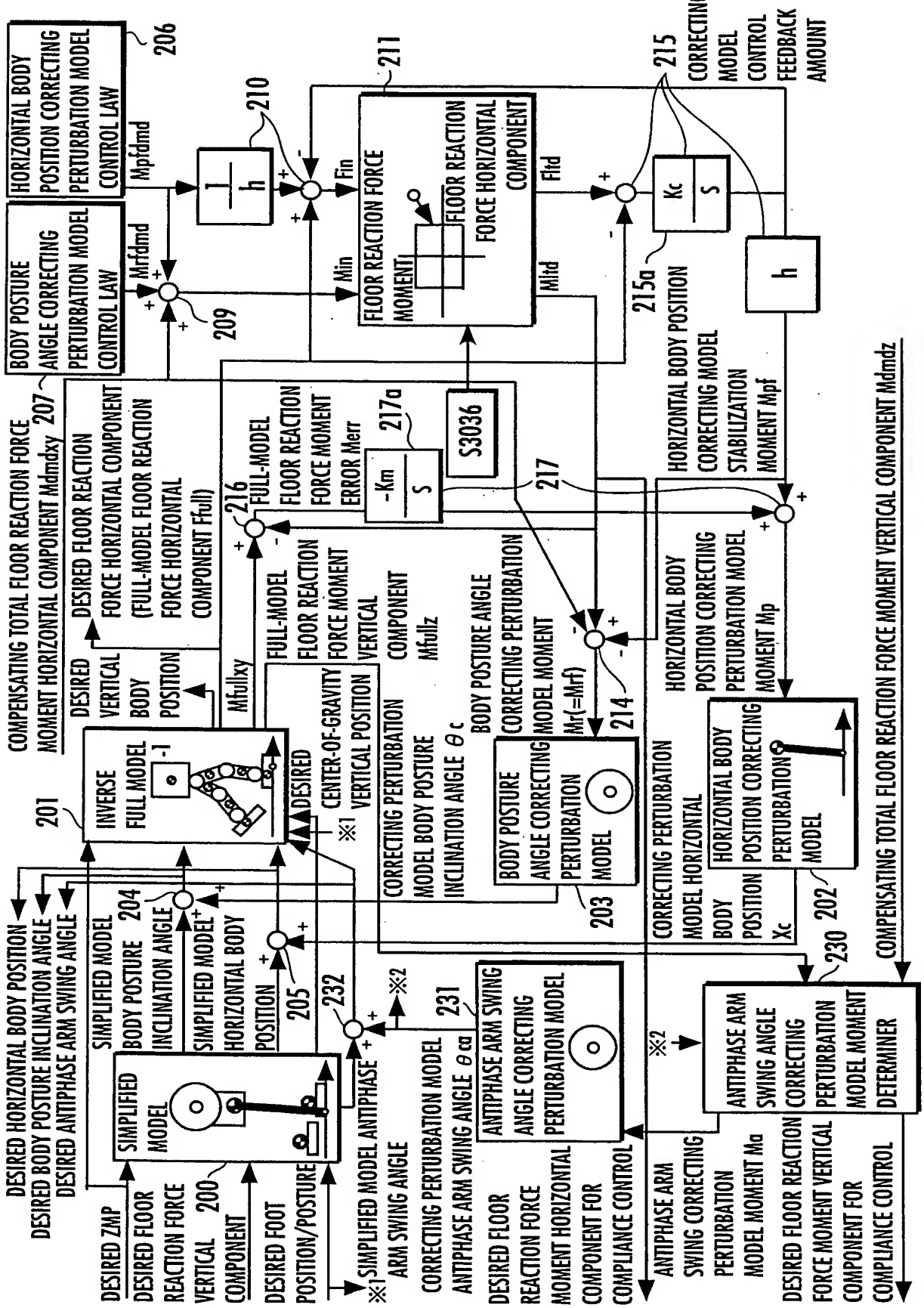

DESIRED HORIZONTAL BODY POSITION
DESIRED BODY POSTURE INCLINATION ANGLE
DESIRED ANTIPHASE ARM SWING ANGLE
DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
DESIRED FOOT POSITION/POSTURE
※1 SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θca
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
ANTIPHASE ARM SWING CORRECTING PERTURBATION MODEL MOMENT Ma
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
DESIRED VERTICAL BODY POSITION
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT (FULL-MODEL FLOOR REACTION FORCE HORIZONTAL COMPONENT Ffull)
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
FULL-MODEL FLOOR REACTION FORCE MOMENT ERROR Merr
CENTER-OF-GRAVITY VERTICAL POSITION
CORRECTING PERTURBATION MODEL BODY POSTURE INCLINATION ANGLE θc
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL MOMENT Mr(=-Mrf)
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL MOMENT Mp
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL
CORRECTING PERTURBATION MODEL HORIZONTAL BODY POSITION Xc
HORIZONTAL BODY CORRECTING MODEL STABILIZATION MOMENT Mpf
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL CONTROL LAW
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
FLOOR REACTION FORCE MOMENT
FLOOR REACTION FORCE HORIZONTAL COMPONENT
CORRECTING MODEL CONTROL FEEDBACK AMOUNT
SIMPLIFIED MODEL
SIMPLIFIED MODEL BODY POSTURE INCLINATION ANGLE
SIMPLIFIED MODEL HORIZONTAL BODY POSITION
INVERSE FULL MODEL -1
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL MOMENT DETERMINER
※1
※2
200
201
202
203
204
205
206
207
209
210
211
214
215
215a
216
217
217a
230
231
232
S3036
Mrfdmd
Mpfdmd
Min
Fin
Mfltd
Fltd
Kc
s
h
-Km

FIG.72

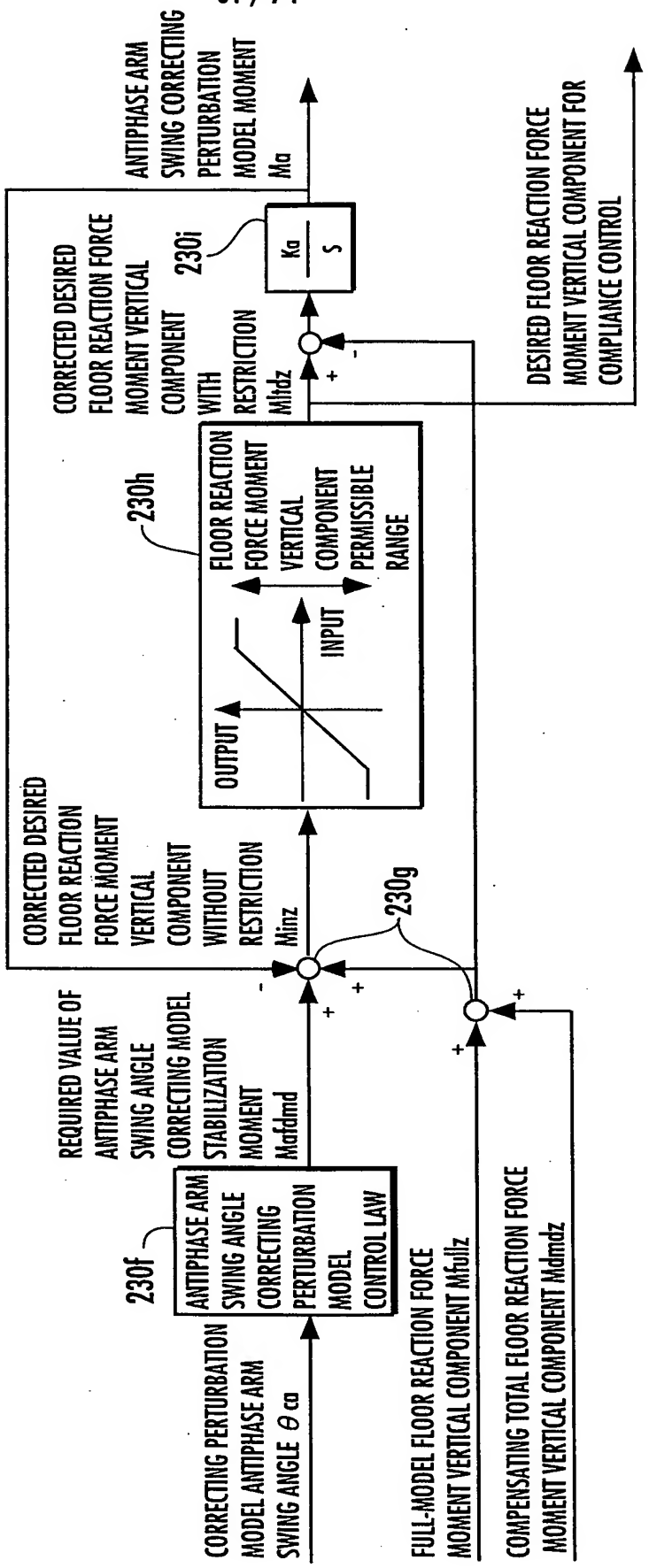

CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θca
230f
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
REQUIRED VALUE OF ANTIPHASE ARM SWING ANGLE CORRECTING MODEL STABILIZATION MOMENT Mafdmd
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITHOUT RESTRICTION Minz
230g
230h
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE
OUTPUT
INPUT
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITH RESTRICTION Mltdz
230i
Ka / s
ANTIPHASE ARM SWING CORRECTING PERTURBATION MODEL MOMENT Ma
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL

FIG.73

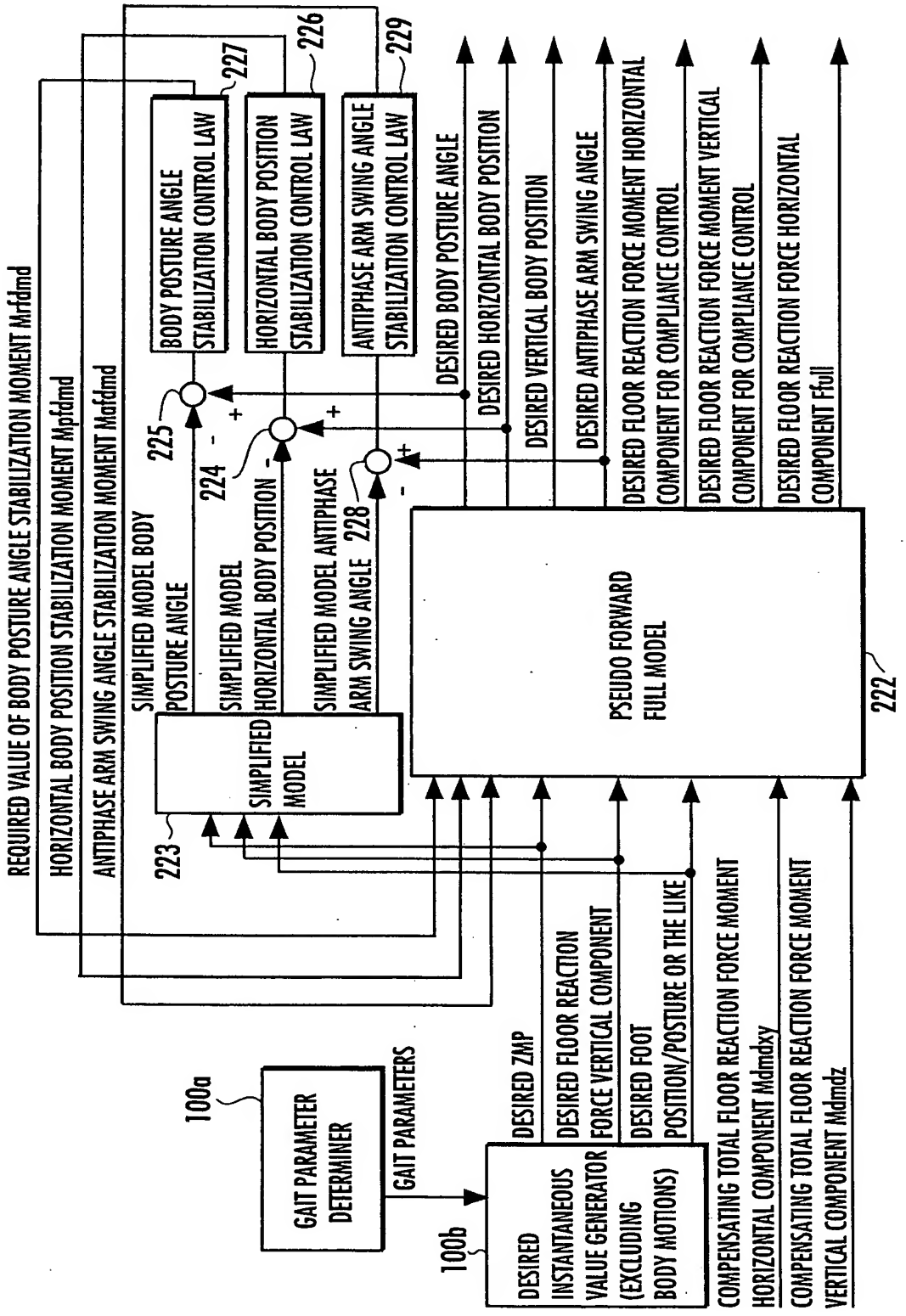

REQUIRED VALUE OF BODY POSTURE ANGLE STABILIZATION MOMENT Mrfdmd
HORIZONTAL BODY POSITION STABILIZATION MOMENT Mpfdmd
ANTIPHASE ARM SWING ANGLE STABILIZATION MOMENT Mafdmd
SIMPLIFIED MODEL BODY POSTURE ANGLE
SIMPLIFIED MODEL HORIZONTAL BODY POSITION
SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE
BODY POSTURE ANGLE STABILIZATION CONTROL LAW
HORIZONTAL BODY POSITION STABILIZATION CONTROL LAW
ANTIPHASE ARM SWING ANGLE STABILIZATION CONTROL LAW
227
226
229
225
224
228
223
SIMPLIFIED MODEL
PSEUDO FORWARD FULL MODEL
222
DESIRED BODY POSTURE ANGLE
DESIRED HORIZONTAL BODY POSITION
DESIRED VERTICAL BODY POSITION
DESIRED ANTIPHASE ARM SWING ANGLE
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT Ffull
100a
GAIT PARAMETER DETERMINER
GAIT PARAMETERS
100b
DESIRED INSTANTANEOUS VALUE GENERATOR (EXCLUDING BODY MOTIONS)
DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
DESIRED FOOT POSITION/POSTURE OR THE LIKE
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz

FIG.74

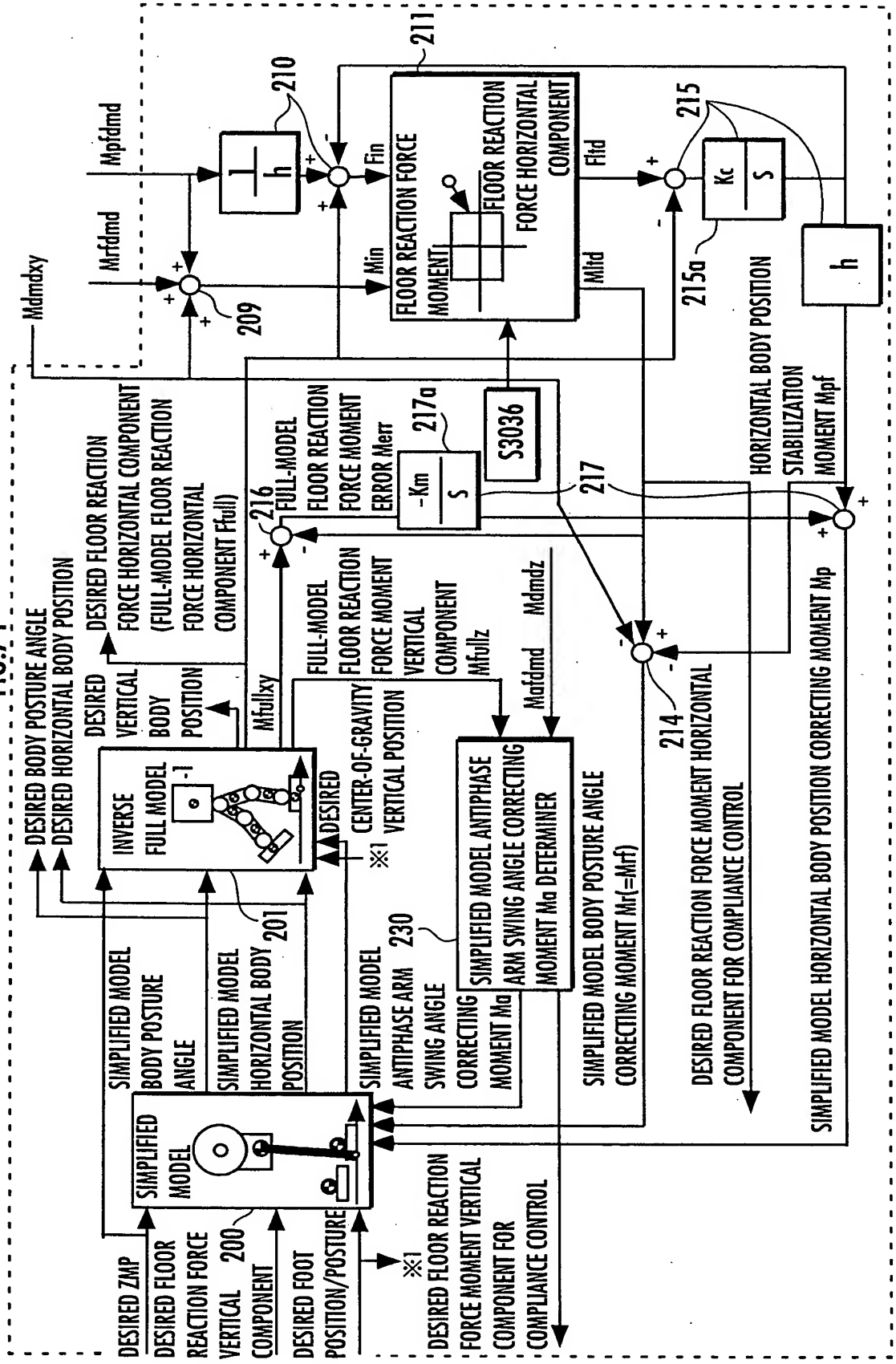

DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
DESIRED FOOT POSITION/POSTURE
200
SIMPLIFIED MODEL
※1
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL
SIMPLIFIED MODEL BODY POSTURE ANGLE
SIMPLIFIED MODEL HORIZONTAL BODY POSITION
201
INVERSE FULL MODEL -1
DESIRED BODY POSTURE ANGLE
DESIRED HORIZONTAL BODY POSITION
DESIRED VERTICAL BODY POSITION
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT (FULL-MODEL FLOOR REACTION FORCE HORIZONTAL COMPONENT Ffull)
Mfullxy
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
※1 CENTER-OF-GRAVITY VERTICAL POSITION
Mafdmd
Mdmdz
SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE CORRECTING MOMENT Ma DETERMINER
230
SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE CORRECTING MOMENT Ma
SIMPLIFIED MODEL BODY POSTURE ANGLE CORRECTING MOMENT Mr(=Mrf)
214
DESIRED FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
SIMPLIFIED MODEL HORIZONTAL BODY POSITION CORRECTING MOMENT Mp
HORIZONTAL BODY POSITION STABILIZATION MOMENT Mpf
h
215
Kc
S
215a
Fltd
FLOOR REACTION FORCE HORIZONTAL COMPONENT
Mltd
FLOOR REACTION FORCE MOMENT
Fin
Min
211
210
1/h
Mpfdmd
Mrfdmd
209
Mdmdxy
216
FULL-MODEL FLOOR REACTION FORCE MOMENT ERROR Merr
217a
-Km
S
S3036
217

FIG.75

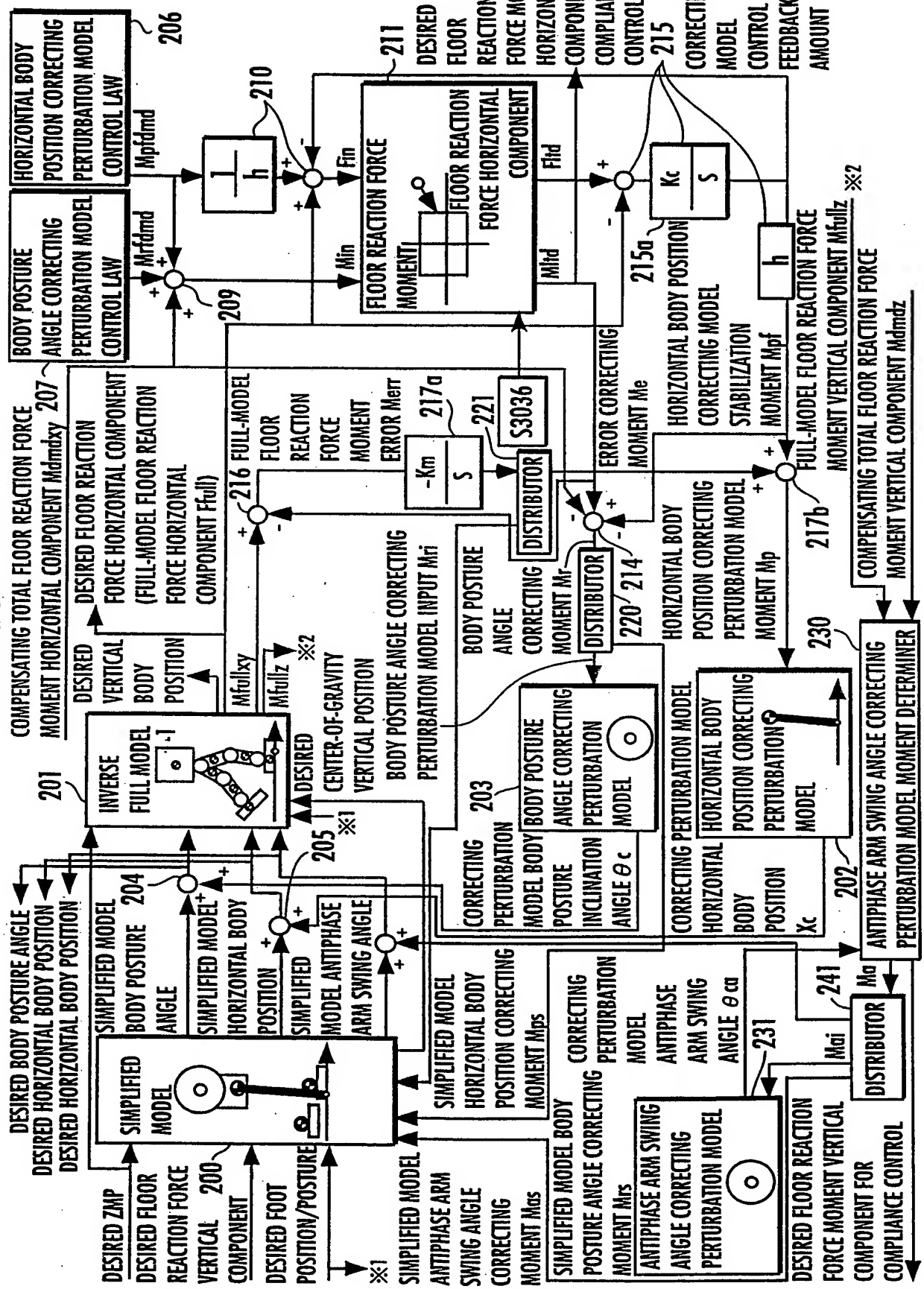

DESIRED BODY POSTURE ANGLE
DESIRED HORIZONTAL BODY POSITION
DESIRED HORIZONTAL BODY POSITION
DESIRED ZMP
DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
DESIRED FOOT POSITION/POSTURE
※1
SIMPLIFIED MODEL ANTIPHASE ARM SWING CORRECTING MOMENT Mas
SIMPLIFIED MODEL BODY POSTURE ANGLE CORRECTING MOMENT Mrs
SIMPLIFIED MODEL HORIZONTAL BODY POSITION CORRECTING MOMENT Mps
SIMPLIFIED MODEL
200
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL
CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θ ca
231
SIMPLIFIED MODEL BODY POSTURE ANGLE
SIMPLIFIED MODEL HORIZONTAL BODY POSITION
SIMPLIFIED MODEL ANTIPHASE ARM SWING ANGLE
204
205
※1
DESIRED CENTER-OF-GRAVITY VERTICAL POSITION
INVERSE FULL MODEL
201
DESIRED VERTICAL BODY POSITION
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
207
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT (FULL-MODEL FLOOR REACTION FORCE HORIZONTAL COMPONENT Ffull)
Mfullxy
Mfullz
※2
216 FULL-MODEL FLOOR REACTION FORCE MOMENT ERROR Merr
217a
-Km / S
221
S3036
DISTRIBUTOR
BODY POSTURE ANGLE CORRECTING MOMENT Mr
DISTRIBUTOR
220
214
ERROR CORRECTING MOMENT Me
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL INPUT Mri
CORRECTING PERTURBATION MODEL BODY POSTURE INCLINATION ANGLE θ c
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL
203
CORRECTING PERTURBATION MODEL HORIZONTAL BODY POSITION Xc
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL
202
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL MOMENT Mp
HORIZONTAL BODY POSITION CORRECTING MODEL STABILIZATION MOMENT Mpf
217b
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
※2
230
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL MOMENT DETERMINER
241
Ma
Mai
DISTRIBUTOR
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL
BODY POSTURE ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
Mrfdmd
209
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL CONTROL LAW
Mpfdmd
206
1/h
210
Fin
Min
FLOOR REACTION FORCE MOMENT
FLOOR REACTION FORCE HORIZONTAL COMPONENT
211
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT FOR COMPLIANCE CONTROL
Flid
Mlid
215
Kc / S
CORRECTING MODEL CONTROL FEEDBACK AMOUNT
215a
HORIZONTAL BODY POSITION
h

FIG.76

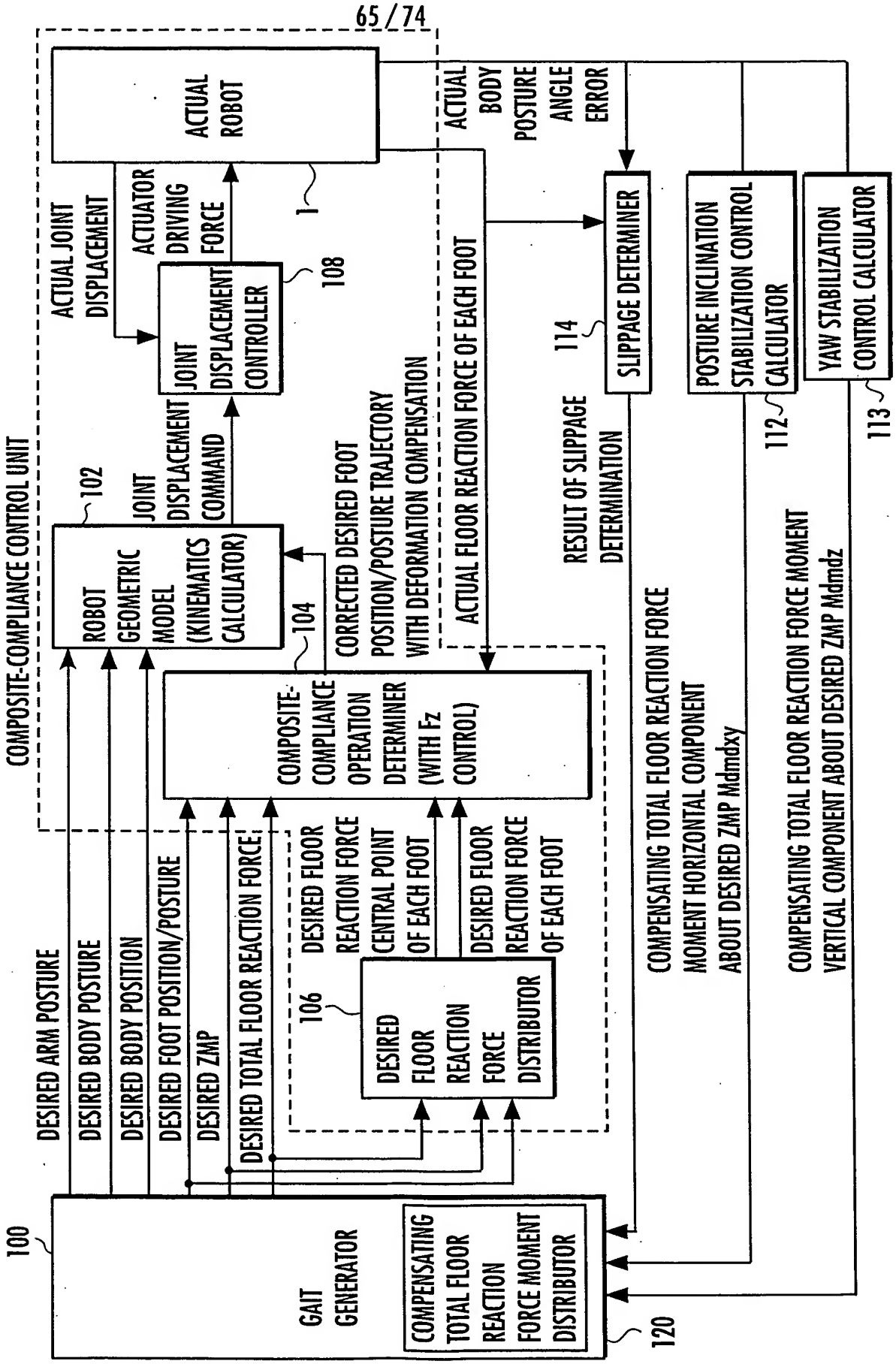

COMPOSITE-COMPLIANCE CONTROL UNIT
ACTUAL ROBOT
1
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
JOINT DISPLACEMENT CONTROLLER
108
ACTUAL BODY POSTURE ANGLE ERROR
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
SLIPPAGE DETERMINER
114
RESULT OF SLIPPAGE DETERMINATION
POSTURE INCLINATION STABILIZATION CONTROL CALCULATOR
112
YAW STABILIZATION CONTROL CALCULATOR
113
102
JOINT DISPLACEMENT COMMAND
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
104
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
DESIRED ARM POSTURE
DESIRED BODY POSTURE
DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
106
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP Mdmdxy
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT ABOUT DESIRED ZMP Mdmdz
100
GAIT GENERATOR
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
120

FIG.77

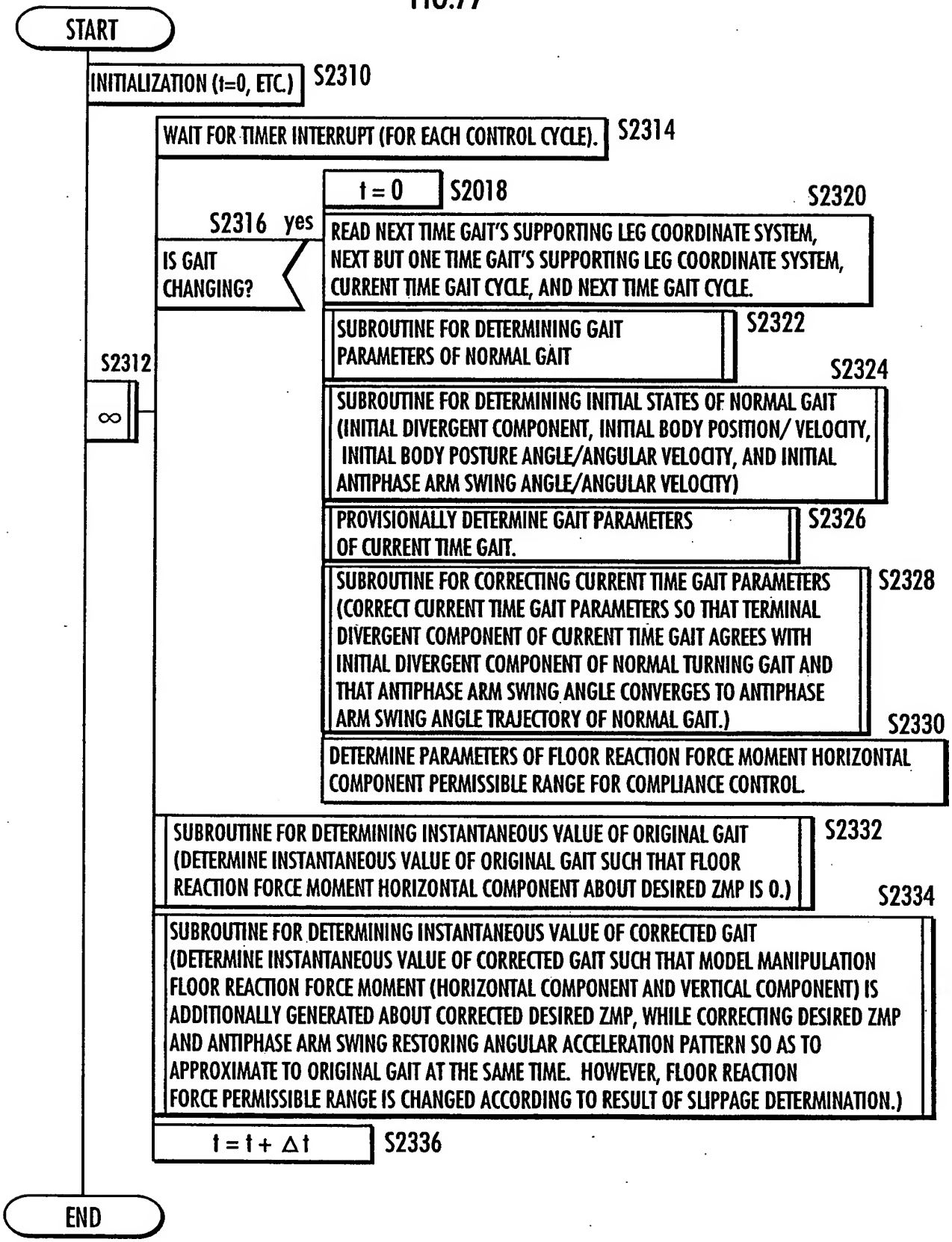

START
INITIALIZATION (t=0, ETC.)
S2310
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S2314
t = 0
S2018
S2316
yes
IS GAIT CHANGING?
S2320
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S2322
S2312
∞
S2324
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S2326
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
S2328
DETERMINE PARAMETERS OF FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE FOR COMPLIANCE CONTROL.
S2330
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF ORIGINAL GAIT (DETERMINE INSTANTANEOUS VALUE OF ORIGINAL GAIT SUCH THAT FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT ABOUT DESIRED ZMP IS 0.)
S2332
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CORRECTED GAIT (DETERMINE INSTANTANEOUS VALUE OF CORRECTED GAIT SUCH THAT MODEL MANIPULATION FLOOR REACTION FORCE MOMENT (HORIZONTAL COMPONENT AND VERTICAL COMPONENT) IS ADDITIONALLY GENERATED ABOUT CORRECTED DESIRED ZMP, WHILE CORRECTING DESIRED ZMP AND ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN SO AS TO APPROXIMATE TO ORIGINAL GAIT AT THE SAME TIME. HOWEVER, FLOOR REACTION FORCE PERMISSIBLE RANGE IS CHANGED ACCORDING TO RESULT OF SLIPPAGE DETERMINATION.)
S2334
t = t + Δt
S2336
END

FIG.78

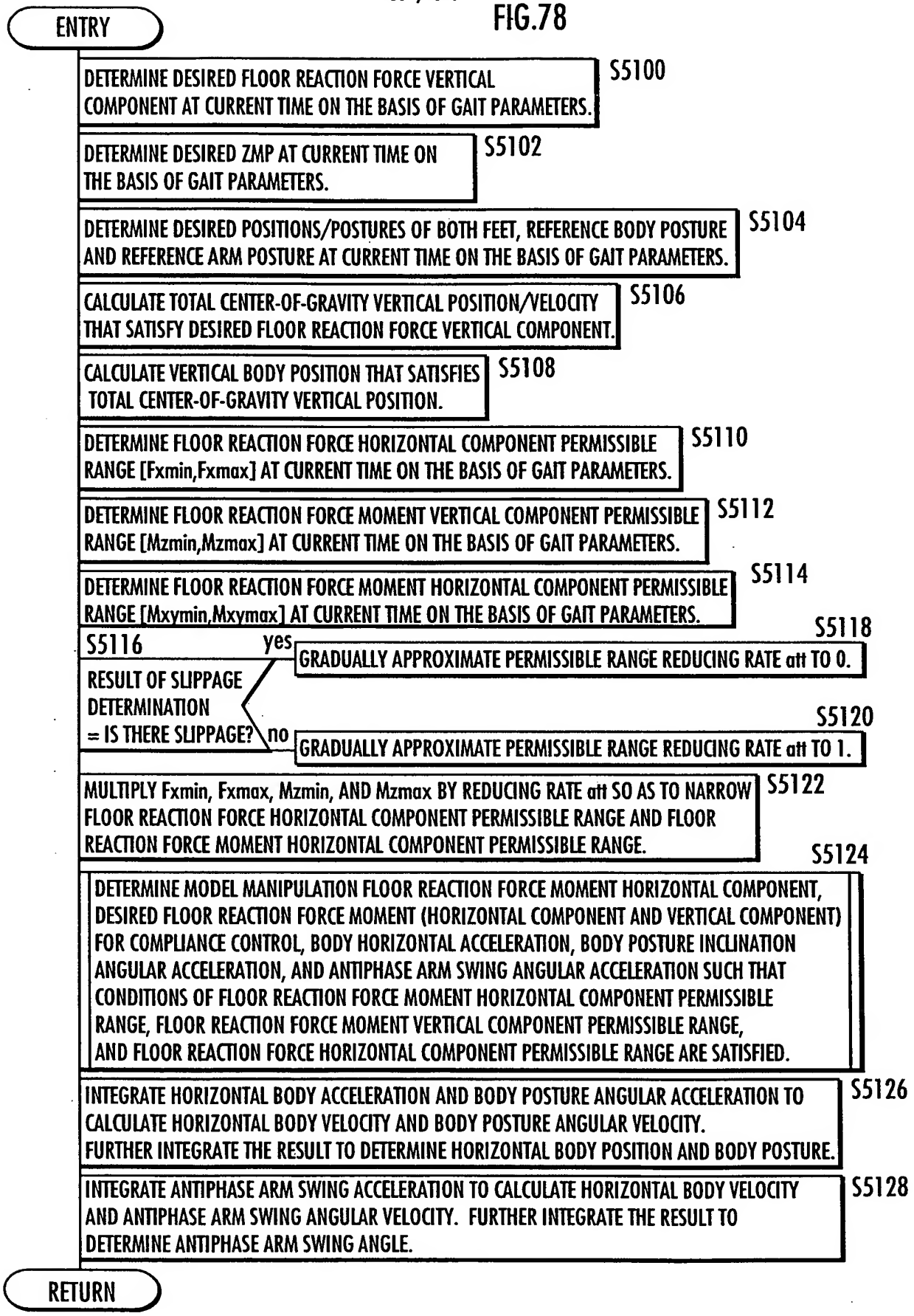

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5100
DETERMINE DESIRED ZMP AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5102
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5104
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S5106
CALCULATE VERTICAL BODY POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S5108
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5110
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5112
DETERMINE FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE [Mxymin,Mxymax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S5114
S5116
RESULT OF SLIPPAGE DETERMINATION = IS THERE SLIPPAGE?
yes
S5118
GRADUALLY APPROXIMATE PERMISSIBLE RANGE REDUCING RATE att TO 0.
no
S5120
GRADUALLY APPROXIMATE PERMISSIBLE RANGE REDUCING RATE att TO 1.
MULTIPLY Fxmin, Fxmax, Mzmin, AND Mzmax BY REDUCING RATE att SO AS TO NARROW FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE AND FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE.
S5122
S5124
DETERMINE MODEL MANIPULATION FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT, DESIRED FLOOR REACTION FORCE MOMENT (HORIZONTAL COMPONENT AND VERTICAL COMPONENT) FOR COMPLIANCE CONTROL, BODY HORIZONTAL ACCELERATION, BODY POSTURE INCLINATION ANGULAR ACCELERATION, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT CONDITIONS OF FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT PERMISSIBLE RANGE, FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE, AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE ARE SATISFIED.
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
S5126
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
S5128
RETURN

FIG.79

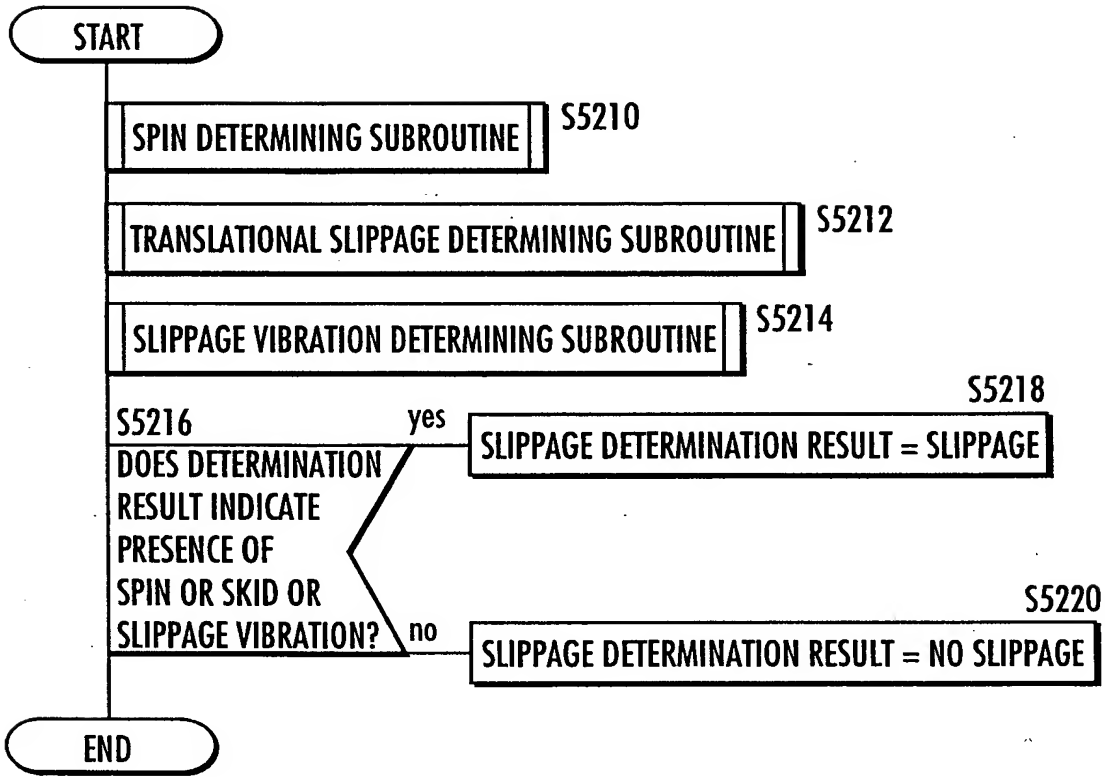

START
SPIN DETERMINING SUBROUTINE
S5210
TRANSLATIONAL SLIPPAGE DETERMINING SUBROUTINE
S5212
SLIPPAGE VIBRATION DETERMINING SUBROUTINE
S5214
S5216
DOES DETERMINATION RESULT INDICATE PRESENCE OF SPIN OR SKID OR SLIPPAGE VIBRATION?
yes
S5218
SLIPPAGE DETERMINATION RESULT = SLIPPAGE
no
S5220
SLIPPAGE DETERMINATION RESULT = NO SLIPPAGE
END

FIG.80

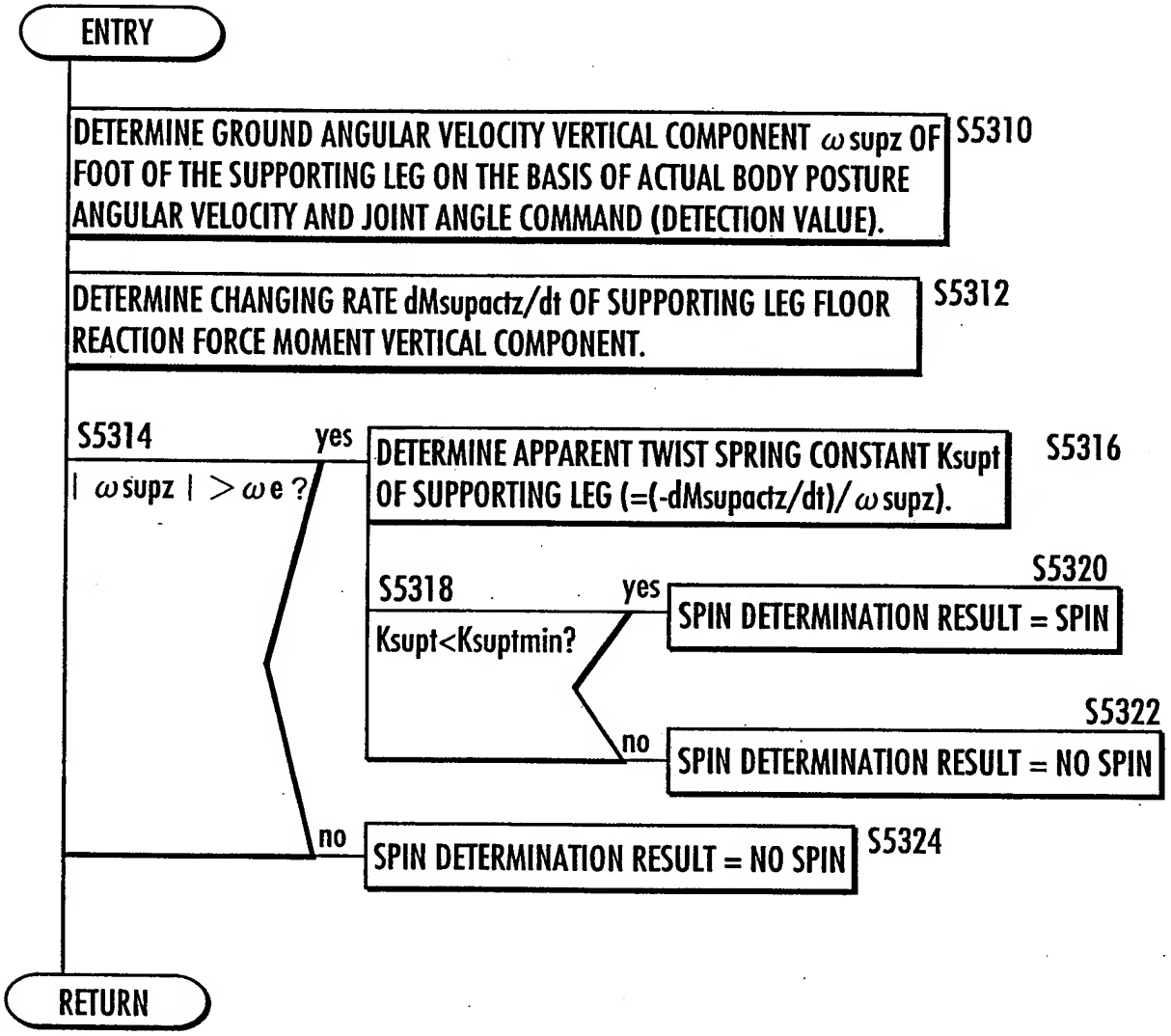

ENTRY
DETERMINE GROUND ANGULAR VELOCITY VERTICAL COMPONENT ωsupz OF FOOT OF THE SUPPORTING LEG ON THE BASIS OF ACTUAL BODY POSTURE ANGULAR VELOCITY AND JOINT ANGLE COMMAND (DETECTION VALUE).
S5310
DETERMINE CHANGING RATE dMsupactz/dt OF SUPPORTING LEG FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT.
S5312
S5314
| ωsupz | > ωe ?
yes
DETERMINE APPARENT TWIST SPRING CONSTANT Ksupt OF SUPPORTING LEG (=(-dMsupactz/dt)/ωsupz).
S5316
S5318
Ksupt<Ksuptmin?
yes
S5320
SPIN DETERMINATION RESULT = SPIN
no
S5322
SPIN DETERMINATION RESULT = NO SPIN
no
SPIN DETERMINATION RESULT = NO SPIN
S5324
RETURN

FIG.81

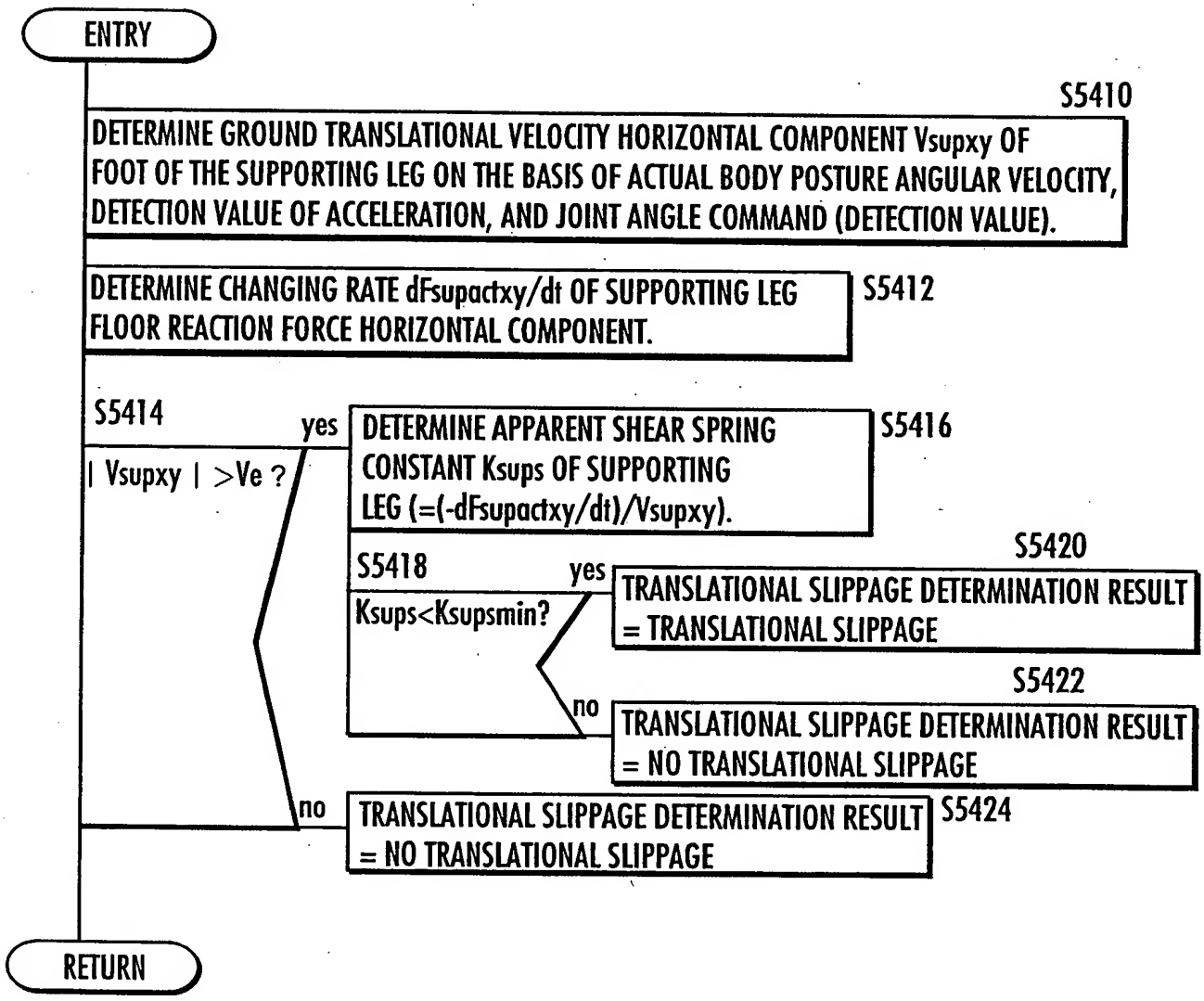

ENTRY
S5410
DETERMINE GROUND TRANSLATIONAL VELOCITY HORIZONTAL COMPONENT Vsupxy OF FOOT OF THE SUPPORTING LEG ON THE BASIS OF ACTUAL BODY POSTURE ANGULAR VELOCITY, DETECTION VALUE OF ACCELERATION, AND JOINT ANGLE COMMAND (DETECTION VALUE).
DETERMINE CHANGING RATE dFsupactxy/dt OF SUPPORTING LEG FLOOR REACTION FORCE HORIZONTAL COMPONENT.
S5412
S5414
| Vsupxy | >Ve ?
yes
DETERMINE APPARENT SHEAR SPRING CONSTANT Ksups OF SUPPORTING LEG (=(-dFsupactxy/dt)/Vsupxy).
S5416
S5418
Ksups<Ksupsmin?
yes
S5420
TRANSLATIONAL SLIPPAGE DETERMINATION RESULT = TRANSLATIONAL SLIPPAGE
no
S5422
TRANSLATIONAL SLIPPAGE DETERMINATION RESULT = NO TRANSLATIONAL SLIPPAGE
no
TRANSLATIONAL SLIPPAGE DETERMINATION RESULT = NO TRANSLATIONAL SLIPPAGE
S5424
RETURN

FIG.82

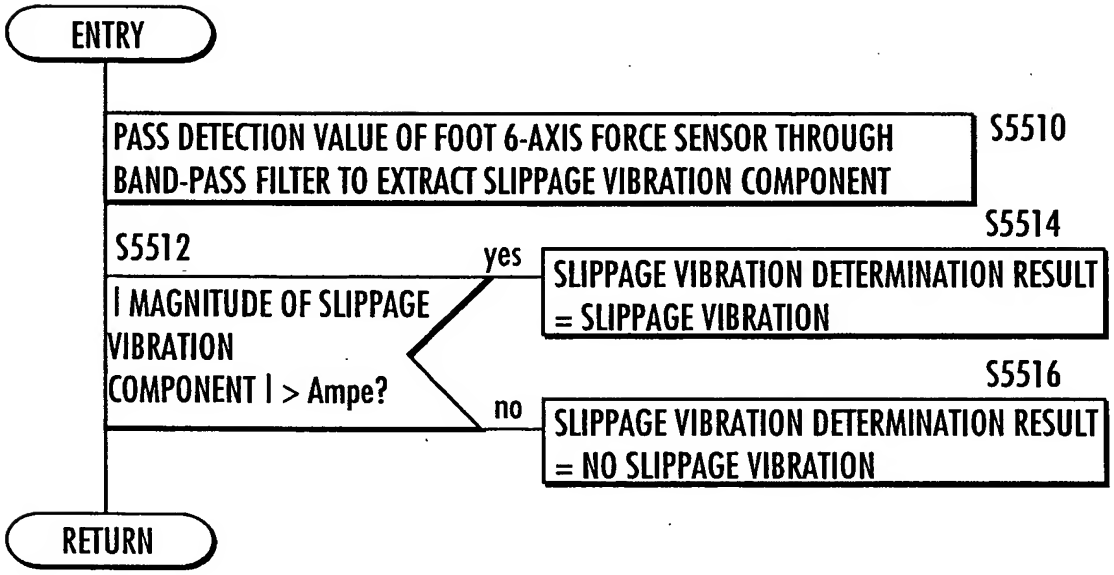

ENTRY
PASS DETECTION VALUE OF FOOT 6-AXIS FORCE SENSOR THROUGH BAND-PASS FILTER TO EXTRACT SLIPPAGE VIBRATION COMPONENT
S5510
S5512
| MAGNITUDE OF SLIPPAGE VIBRATION COMPONENT | > Ampe?
yes
S5514
SLIPPAGE VIBRATION DETERMINATION RESULT = SLIPPAGE VIBRATION
no
S5516
SLIPPAGE VIBRATION DETERMINATION RESULT = NO SLIPPAGE VIBRATION
RETURN

FIG.83

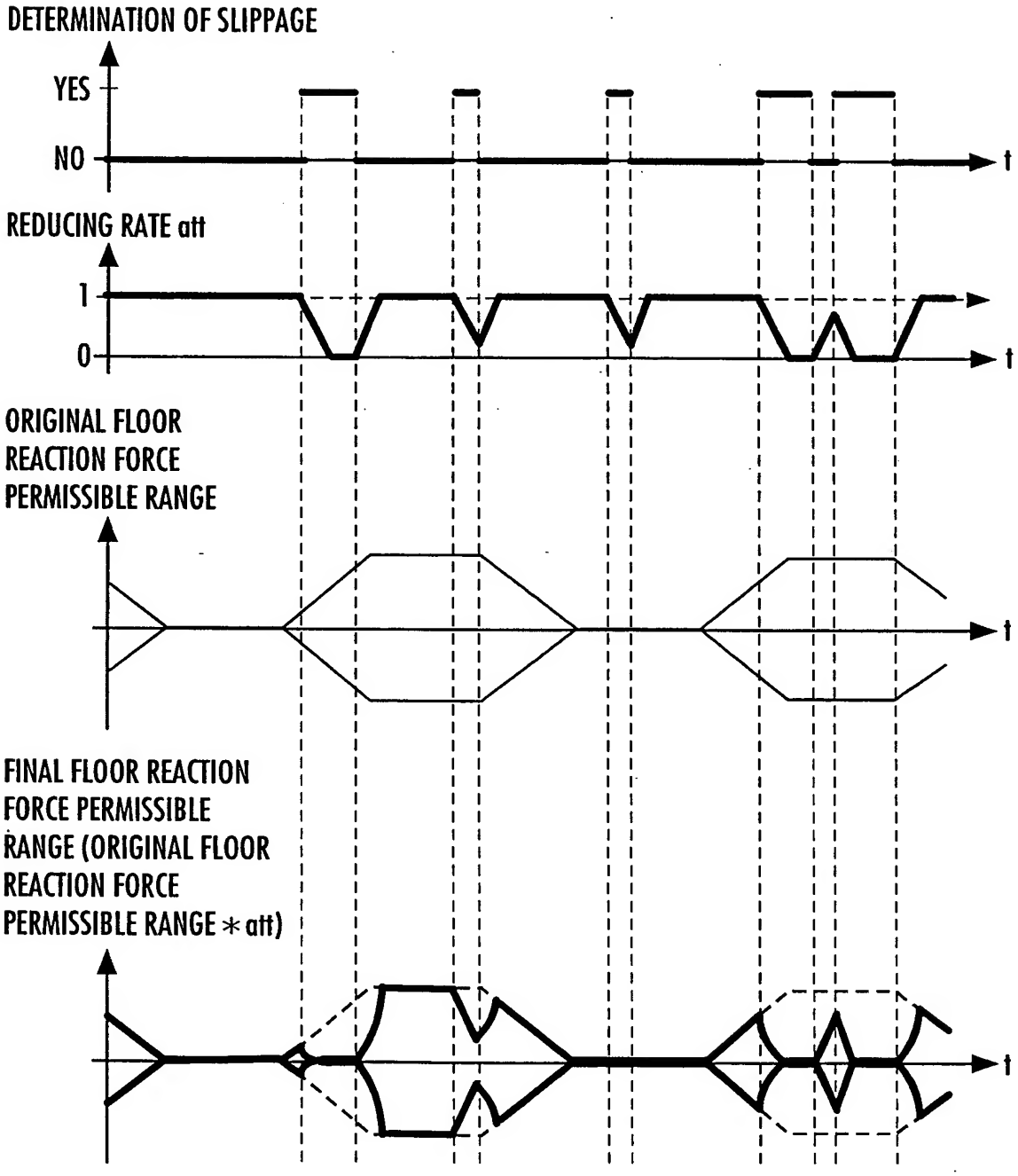

DETERMINATION OF SLIPPAGE
YES
NO
t
REDUCING RATE att
1
0
t
ORIGINAL FLOOR REACTION FORCE PERMISSIBLE RANGE
t
FINAL FLOOR REACTION FORCE PERMISSIBLE RANGE (ORIGINAL FLOOR REACTION FORCE PERMISSIBLE RANGE * att)
t

FIG.84

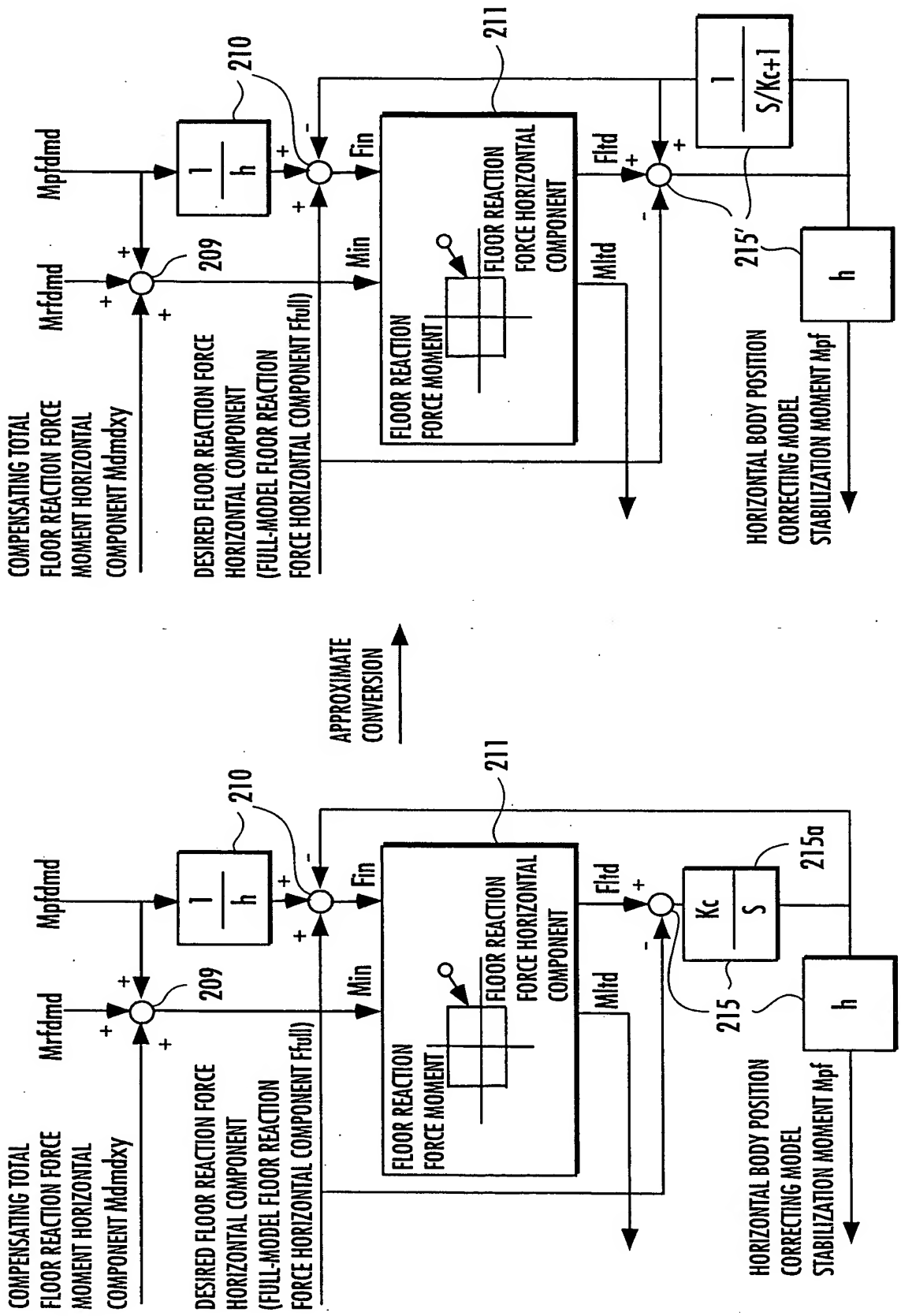
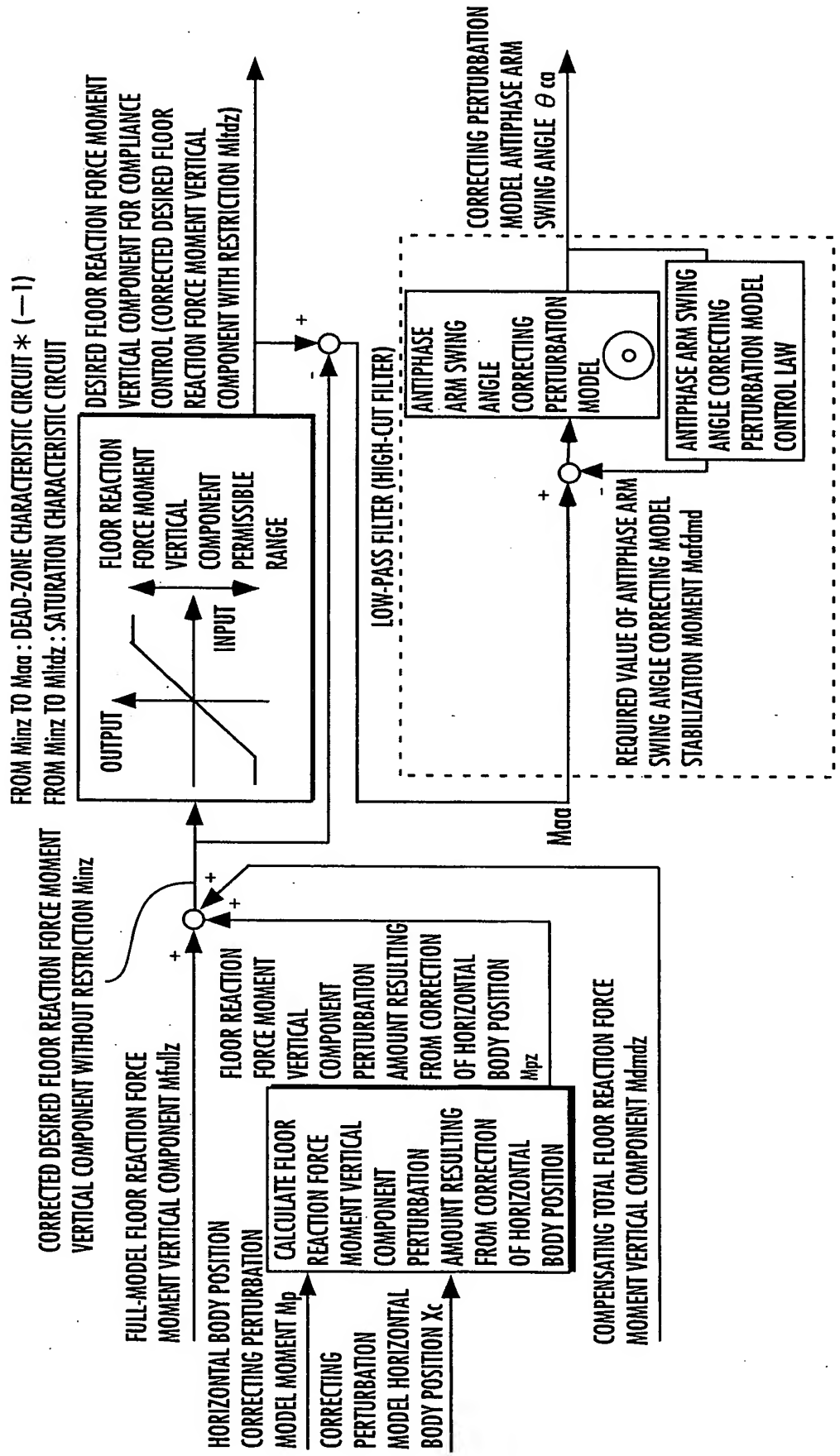

COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT HORIZONTAL COMPONENT Mdmdxy
DESIRED FLOOR REACTION FORCE HORIZONTAL COMPONENT (FULL-MODEL FLOOR REACTION FORCE HORIZONTAL COMPONENT Ftdl)
Mrfdmd
Mpfdmd
209
210
211
Fin
Min
Mltd
Fltd
FLOOR REACTION FORCE MOMENT
FLOOR REACTION FORCE HORIZONTAL COMPONENT
1/h
1/(S/Kc+1)
Kc/S
215
215'
215a
h
HORIZONTAL BODY POSITION CORRECTING MODEL STABILIZATION MOMENT Mpf
APPROXIMATE CONVERSION

FIG.85


FROM Minz TO Maa : DEAD-ZONE CHARACTERISTIC CIRCUIT * (−1)
FROM Minz TO Mitdz : SATURATION CHARACTERISTIC CIRCUIT
DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT FOR COMPLIANCE CONTROL (CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITH RESTRICTION Mitdz)
OUTPUT
INPUT
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE
LOW-PASS FILTER (HIGH-CUT FILTER)
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL
CORRECTING PERTURBATION MODEL ANTIPHASE ARM SWING ANGLE θ αa
ANTIPHASE ARM SWING ANGLE CORRECTING PERTURBATION MODEL CONTROL LAW
REQUIRED VALUE OF ANTIPHASE ARM SWING ANGLE CORRECTING MODEL STABILIZATION MOMENT Mafdmd
Maa
CORRECTED DESIRED FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT WITHOUT RESTRICTION Minz
FULL-MODEL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mfullz
HORIZONTAL BODY POSITION CORRECTING PERTURBATION MODEL MOMENT Mp
CORRECTING PERTURBATION MODEL HORIZONTAL BODY POSITION Xc
CALCULATE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERTURBATION AMOUNT RESULTING FROM CORRECTION OF HORIZONTAL BODY POSITION
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERTURBATION AMOUNT RESULTING FROM CORRECTION OF HORIZONTAL BODY POSITION Mpz
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mdmdz